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PHILOSOPHY

OF THE

MECHANICS OF NATURE,

AND

THE SOURCE AND MODES OF ACTION

OF

NATURAL MOTIVE-POWER.

BY Z. ALLEN.

ILLUSTRATED WITH NUMEROUS WOOD-CUTS.

"In order to discover the principles on which the Mechanical Sciences truly rest, we must examine the nature and origin of our knowledge of causes."—*Whewell.*

"Nor is it possible that men should avail themselves fully of the POWERS which are in Nature without knowing the cause of these Powers."

NEW-YORK:
D. APPLETON AND COMPANY,
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PREFACE.

Many of the chapters of this treatise on the Philosophy of the Mechanics of Nature were written ten or twelve years ago. Recent discoveries in science have been incorporated into the original sketches, to complete them.

In tracing out the source of Natural Motive-Power, the final result has been so different from what was originally anticipated by the writer, on commencing the task, and so unlike the popularly-adopted theories taught in the text-books of the Physical Sciences, that the manuscript was laid aside for re-examination. The revisal has required a considerable period of time, and prolonged labor.

The printing of this work having been necessarily accomplished with dispatch in a distant city, and with a limited command of time, the writer feels less responsible for the errors of the press, than for the principles advanced in the discussion of the subjects.

For the use of several wood-cuts, the writer tenders his acknowledgments to Dr. Hare and to Professor Joseph Henry, of the Smithsonian Institution.

Facts and discoveries, gleaned from the pages of numerous scientific Journals and Treatises, have been synthetically arranged into a system, corroborative of general principles. These general principles, in turn, have been subjected to analytical verification.

In pursuing this plan, it was speedily apparent that it would lead to the adoption of a doctrine of the propagation of mechanical action between portions of matter, utterly at variance with the popular theories at present taught in our colleges and schools.

The laws of Mechanical Science establish that "matter at rest cannot put itself in motion." In opposition to this doctrine, the laws of the science of chemistry establish the existence of "Inherent Forces," and of "three Imponderable Agents," Heat, Light, and Electricity.

Gravitation and Cohesion are also admitted, in popular treatises on Natural Philosophy, to be "Forces Inherent in Matter."

It is manifest, in carrying out the *mechanical* law of the incapability of matter to move itself, that all the movements of terrestrial matter must originate from a cause external to the mass of the earth.

The laws of Chemical Science, in affirming that "Inherent Forces" and "Imponderable Agents" exist in connection with terrestrial matter, and produce the relative states of motion and rest of all such matter, contravene this primary mechanical Law.

Hence, Mechanical and Chemical Sciences are at issue in their respective doctrines, and the one or the other must be essentially erroneous for, in the admirable economy of nature, two causes are never found to be employed to produce an identical effect.

By tracing out the continuous propagation of the solar action upon terrestrial matter, throughout successive modifications of static and dynamic conditions of groupings of atoms into fuel, food, steamy vapors in the sky, crystals, &c., it admits of demonstration that all the preceding "Inherent Forces" and "Imponderable Agents" are resolvable simply into "*the propagation of mechanical action through the medium of electric matter.*"

Philosophers appear, therefore, to have lost sight of the preceding primary law of Mechanical Science, in pursuing their investigations. By steadfastly following the guidance of the old and well-established principles of this science, we are finally led to the recognition of the sublime plans adopted by an Infinitely Intelligent Creator for perfecting the operation of the mechanisms of his universe.

The facts and principles developed in the present work are such as every intelligent person should know, connected as they are, with the most wonderful discoveries of the present age.

Z. ALLEN.

PROVIDENCE, Rhode Island,
October 4th, 1851.

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PHILOSOPHY
OF THE
MECHANICS OF NATURE.

INTRODUCTION.

> "By ceaseless action all that is subsists."
>
> COWPER.

FACTS OF THE PERPETUAL MOTION OF THE MATTER CONSTITUTING THE UNIVERSE.

ON looking abroad upon the visible universe, amid which we find ourselves existing, we behold all parts of it to be in motion. Streams of water appear leaping in cascades from the hillsides, and sweeping in their courses through the vales. The passing breeze stirs the locks on our temples,—bends the rugged oaks of the forests, and hurries along the flitting clouds above the mountain-tops. The flowing tides never cease to heave, as it were with the pulsations of life, the swelling and subsiding bosom of the ocean; whilst the waves ever lash the sounding shores. The whole mass of the earth, with its mountains, plains, rivers, and oceans, is ceaselessly whirled on its axis, and in its circular orbit around the sun, with a velocity of more than a thousand miles in each successive minute of time. The other planets of the solar system are similarly urged with corresponding velocities in their respective orbits; whilst the sun itself,—the centre of motion of these revolving orbs, is discovered to be hurrying away, with its train of surrounding planets, in the direction toward the constellation of Hercules. And, finally, even the once-termed "fixed stars," have been recently discovered, by means of improved astronomical instruments, to partake of this universal motion.

Wherever matter is discoverable, it is thus found to be restless.

The huge orbs of matter constituting the worlds of the visible universe, are readily discoverable to be moving in circular orbits about the sun, with such orderly and machine-like regularity, that the descriptive appellation of "Mechanism of the Heavens," has been applied to them by La Place.

Nor is this exhibition of the machine-like regularity of the directions of the movements of matter confined to the sublime masses in the free space of the heavens; for the same perfect regularity of systematically-directed impulses controls the states of motion and rest of every individual particle of terrestrial matter, arranging liquid particles into spherical globules, as in the falling rain-drop, and solid masses into beautiful angular symmetrical crystals, as observable by the aid of the microscope in the flake of falling snow, and in mineral crystallizations.

Among the spectacles that earliest excite the admiration of the intelligent child, is that of the frostwork pencilled on wintry mornings, in glittering angular lines, upon the nursery window-panes, through which he first looks forth, to gain a knowledge of the external world. After gazing with wonder upon the exactly regular angles of the radiating lines, sometimes producing outlines of the branches and foliage of trees, of animals, church-spires, and other objects, which the lively imaginings of childish fancy readily suggest, the little inquisitive observer rarely fails to ask the question, "who did it?" And it is rare that any other answer is given to his first philosophical inquiry into the natural cause of the states of motion and rest of matter, than a brief ascription of it to the agency of "Jack Frost."

When transferred to the school-room, he is next taught to ascribe the same phenomena of the fixation of atoms into solid masses to another fictitious agent of nature—"COHESION." And the same system continues to be progressively extended, by ascribing the phenomena of the movement of a falling stone toward the centre of the earth to still another agency of nature—"GRAVITATION." And this system of suggesting the existence of various other special agencies of nature, for the sole purpose of ascribing thereto the several physical phenomena of HEAT, LIGHT, ELECTRICITY, CHEMICAL AFFINITY, MAGNETISM, &c., has been extended throughout all the physical sciences.

And, what is still more remarkable, the same names are applied to denote both the causes of these several phenomena, and the effects thereby produced; thus, confusedly blending ideas of the causes and effects of heat, cohesion, light, &c.

Thus early and systematically is human intelligence misdirected in the pursuit of knowledge, and led to believe in numerous fictitious agencies of nature.

Irreconcilable contradictions, also, are presented to the student at the very threshold of some of the sciences. In learning the elementary principles of the science of mechanics, he is taught that matter is "inert;" "matter at rest cannot put itself in motion," &c.; and in the rudiments of the science of chemistry, the relative movements of the atoms of matter at insensible distances, are ascribed to "inherent forces" and "chemical action," as causing their self-originating and self-directed movements.

These discrepancies and difficulties, with the rapid progress of modern science, have become impediments in the path of the student, which it is important to clear away, to impart to the physical sciences a more perfect system of accordance and truthfulness, which constitutes the peculiar charm of the exact science of mathematics.

There are, doubtlessly, as perfectly systematic mechanical laws, governing with unvarying exactitude the operation of the causes producing all the phenomena of the states of motion and rest of terrestrial matter, as are the systematic unvarying rules governing the demonstrations of the problems of mathematics; and consequently every discrepancy of science with facts verified experimentally, must originate from mistakes or untruthful doctrines. There are no mistakes in the working of the machinery of nature. Indeed, the very term *mechanics*, as applied to the branch of science treating of the states of motion and rest of matter, is derived from the Greek word MECHANE, signifying *ma-*

chine, the ancient philosophers having had recourse to certain contrivances of mechanism to test their theoretical calculations of the movements of bodies, producible by variously modified impulses of force.

Hence originated two very important subdivisions of the science of MECHANICS, viz., *theoretical* and *practical.*

Theoretical Mechanics embraces the consideration of the mathematical principles of the action and reaction of forces in producing the phenomena of the relative movements of matter, where there is no friction, resisting medium, &c., to be taken into account. The calculations of the movements of the orbs of matter in the free space of the heavens admit of admirable perfection of the application of theoretical calculations and mathematical formulae, for determining their movements and perturbations.

But terrestrial mechanics, on the contrary, involve the consideration of friction,—of a resisting atmosphere,—of strength of materials, states of fluidity, of heat, and counteracting impulses denominated "attraction" and "repulsion" of electrical forces. An accurate knowledge of all of these disturbing causes is absolutely necessary, and must be allowed for in every calculation of terrestrial mechanics, to insure perfect truthfulness. Some of these causes of the phenomena of the relative movements of portions of matter *toward*, *from*, and *about each other's centres*, denoted by the popular terms, ATTRACTION, REPULSION, and POLARITY, remain as yet so imperfectly understood and explained, that terrestrial Mechanics is involved in a labyrinth of difficulties, which require the utmost sagacity of the human intellect to appreciate.

As all the relative movements of atoms at insensible distances, and of masses at sensible distances, naturally taking place around us, are more or less either caused or controlled, by these influences, it is manifest that the science of the Mechanics of Nature comes under the subdivision of Practical Mechanics, and includes within its scope a complete consideration of every cause which affects the state of rest and motion of terrestrial matter.

In treating of the mechanics of nature, as in treating of the artificial applications of the science of mechanics, it has been found convenient to consider of the action of equal counteracting forces, producing *the counterbalanced state of rest of matter*, and of forces which cause actual *movements of matter*, under two distinct heads: the former being denominated STATICS, derived from a Greek verb, signifying *I stand still*, and the latter DYNAMICS, from another Greek word, signifying FORCE or POWER, as a cause of motion.

The term *force*, or *power*, therefore, denotes whatever produces, in any portion of matter at rest, a tendency to move, or to occupy successive portions of space; or in any portion of matter in motion, a tendency to occupy successive portions of space, in any way differing from a uniform movement in a straight line.

Force or *power* is therefore the immediate precedent cause of the *effect of motion of matter.*

As there is no portion of matter of the visible universe in an *absolute state of rest*, it is manifest that this branch of the subdivision of the science of the mechanics of nature must be considered only as a *relative condition* of rest of portions of matter.

Motion and rest being simply effects produced of the occupancy by *matter* of successive portions of *space* in successive portions of *time*, SPACE, TIME, and MATTER, are essential elements to be taken primarily into consideration, in pursuing practical investigations into the science of the MECHANICS OF NATURE.

SPACE AND TIME

CONSIDERED AS ELEMENTS OF THE SCIENCE OF MECHANICS.

INFINITE SPACE.

> "Without bound,
> Without dimension; where length, breadth, and height,
> And time and place are lost."—MILTON.

THE philosophical definition usually given of SPACE is, "extension without limits, uniformly similar in all its parts, and void of all elements of matter." Space, when thus considered as unoccupied, is termed "*Absolute Space.*"

The idea of *absolute* space, unoccupied by a single living being, and by a single particle of matter, suggests such a state of cheerless vacuity—of unbroken silence—of absence of all movements, and of all enjoyments and sympathies of sentient beings, that the principle of intelligence or mind recoils from the contemplation of the supposition of a universal void; and rejoices in the relief afforded by the contemplation of the occupancy of space by other kindred intelligences, and by a FIRST CAUSE, or CREATOR, and also by the beautifully arranged mechanism of the universe.

The presence throughout all space of a supervising intelligence, to plan out and sustain the beautiful systems, and the orderly arrangements of matter, and their orderly workings as mechanisms, is one of the first and most sublime truths recognized by human intelligence; founded on the primary law of mechanical science, that "*matter cannot put itself in motion.*"

Although all space must be considered to be pervaded by an Omnipresent Power, yet it has not been deemed expedient by the Great First Cause to endue subordinate intelligent beings on this earth with organs of perception adequate to discovering the actual occupancy of any portions of space by his presence therein. This remarkable fact manifests an apparent design to leave the discovery of the existence of an Omnipotent Power to the reason of the intelligent beings, who are thus left to act as free agents on this planet, without being immediately overawed by his overwhelming presence.

Whenever we attempt to form a conception of infinite extent of space, we feel our limited faculties of intelligence to be incompetent in every way to embrace the idea of INFINITY. We very naturally commence the attempt, by adding together a series of linear admeasurements of the most extensive known intervals of space, such as the distance of the remotest visible stars, the light of which only reaches our planet in the form of a nebulous haze, like that of the "*milky-way*" in the heavens.

Astronomers have calculated that, with the ascertained speed of the transmission of the influence recognized by the action on the material nerves of the eye as the phenomenon of light, (at the rate of 12,000,000 miles per minute,) a period of several hundreds of years must elapse for this influence to become extended through the wide interval of space that separates this earth from the remotest visible stars. We may imagine similar huge intervals of space to be extended beyond the remotest of these dimly visible stars, in a successive series, each equal in number to the intervening miles between such distant stars and our planet. After grasping the idea of this sublime extent of space, it remains still to add series to series of similar extents of space, continually, until, whilst thus occupied, we may imagine our heads to become blanched with the silvery hairs of age;—and still the task of computation of infinity would be only begun.

Thus this attempt becomes finally directed to the calculation of the series of ages requisite for continuing the computation, until another infinity,—the *infinity of time,—eternity*—becomes a prerequisite for estimating infinite space.

Finite beings realize that they have the command of only brief periods of finite time; and with reasoning powers bewildered, and aching heads, they draw back from the attempt of estimating both the extent of infinite space, and of infinite time, impressed with the overwhelming idea, that all the space occupied by the solar system is actually too minute to be noticed as an element of the computation of infinite space.

A circle formed by the figure of a serpent, with his tail recurved to his mouth, was a favorite emblem adopted in Egyptian hieroglyphics to represent *eternity*, or continuity without beginning, and without end. Although this illustration is sufficiently distinct to convey an idea of a line without beginning and without end, yet it is only the artifice of the circle of signatures, denominated the *round robin*, purposely devised to *conceal the beginning and the end.*

If none of the material or immaterial existences of the universe had been created, still we cannot help supposing that time would have continued to go on unceasingly, like a river in a desert, although no sentient beings existed on the shores to note its progress.

Thus, in every attempt to grasp at the idea of INFINITY, we fail of winning a glimpse of the ever-receding bourn; and if the attempt be persisted in, the intellectual powers may become wrecked amid metaphysical speculations.

FINITE SPACE AND TIME.

Equally inadequate are human powers of perception for appreciating the minutest portions of space and time, as for appreciating infinity.

Mr. Watts observes, in his Treatise on Logic, "The least part of space sets all the philosophers at variance, when they attempt to tell what it is;" and "it helps not our ignorance to feign a knowledge where we have none, by making a noise about sounds without clear and distinct significations."

Human nerves of sensation are not susceptible of distinct impressions of portions of time shorter than about one-tenth of a second. When impressions on the nerves of sensation are repeated oftener than this, they become continuously blended. By the rapidly repeated vibrations of the strings of various musica instruments, the successive impulses imparted to the materia nerves of the ear are recognizable only as one continuous impulse, uniform *tone*, or *note*. A rapidly whirled firebrand, instead of affecting the material nerves of the eye with the sensation or perception of a progressive circular movement ove distinct portions of space in distinct intervals of time, produce the perception of a continuous circle of fire.

Numerous facts of the above description prove conclusively, that as the human faculties of perception are inadequate to comprehending infinitely great magnitudes, on the one hand, so they are equally inadequate, on the other hand, to distinguishing minute portions of time, or even a *minute atom* of the masses of matter occupying perceptible portions of space; as will be illustrated when we come to consider the OCCUPANCY OF SPACE BY MATTER.

If such be the constitutional limits of the powers of human perception, it becomes very manifest, that they are inadequate, on the one hand, to observing how natural forces act between imperceptibly small elementary atoms at *insensible* distances from each other, or between the huge masses of such atoms, with millions of miles of space intervening between them, when such forces are transmitted with a velocity of 12,000,000 miles in one minute of time, as occurs in the propagation of mechanical action to the material nerves of the eye, recognizable as the sensation or perception of light.

Although denied the possession of faculties of perception adequate to recognizing directly the modes of action of the subtile causes of motive power, that produce the various states of relative rest and motion of the matter accompanying space, and constituting the visible universe around us, yet we feel conscious of our ability to arrange and classify the palpable effects produced by such causes of motive power, and to reason from analogies of mechanical causes and effects; so as to enable us to establish determinate laws to serve as landmarks, whereby we may extend with confidence our explorations into apparently mysterious and incomprehensible fields of physical science. So far, therefore, is this circumstance of the limited extent of the direct powers of human perception from being a discouragement in the pursuit of knowledge, it seems to be rather an evidence of a manifest design of the Great First Cause to have thus constituted the powers of human perceptions purposely to allow of the exercise of reason and intelligence in arriving at a knowledge of the sublime and perfect attributes of his powers; and to allow, also, of the refined pleasures derivable from gradually drawing aside the curtain, that conceals the curiously planned mechanical arrangements devised by omnipotent power and wisdom.

The immediate corporeal strength or POWER of a man is comparatively feeble. Few men can carry a heavier weight than three or four hundred pounds. But they have command of a considerable portion of SPACE and TIME, whilst existing on the surface of the earth. A man may conveniently traverse a space of two or three miles in the period of one hour of time; during which prolonged interval, he may continuously operate the lever-bar of the apparatus of screws, or of an hydraulic press, employed for lifting a ship from the water. By this continuous application of his corporeal strength, he may succeed in lifting a heavy mass, which his whole strength, directly applied, would not enable him to stir at all.

The possession of this command of *space* and *time* to operate in, constitutes, to a certain extent, an advantage equivalent to the possession of great corporeal strength, by commuting the small extent of motive power of which a man may have the continuous command, for gaining possession of an effective sum of motive power that he could not otherwise command.

All the various kinds of machinery for lifting heavy weights, constitute so many different devices for bartering a series of feeble impulses, through the medium of SPACE and TIME, to obtain the sum of them in an equivalent of aggregate POWER.

The whole force exerted by a powerful horse has been estimated by engineers to be adequate to raising, within 1 minute of time, a weight of 33,000 lbs. through a height of 1 foot of space; or, *vice versa*, of raising a weight of 1 lb. through a height of 33,000 feet of SPACE in 1 minute of TIME. With a knowledge of these mechanical equivalents of SPACES and TIMES, the engineer may so commute space and time as to render available, at his pleasure, a pack-thread, or a cable, to transmit the motive power of a horse to act at a distance; and he may thus have all this scope in the selection of the strength of materials available for propagating impulses of motive power to a distance.

Although these applications of the principles of the science of motion and force are more appropriately considered in the mechanics of the useful arts, yet they are found to be invariably adopted as the essential basis of the practical details of the mechanics of nature.

This commutation of Matter, Space, and Time, constitutes VELOCITY.

The employment of these elements of the science of mechanics, hitherto very little studied in artificial appliances of machinery, is wonderfully carried out in the operations of the natural mechanism of the universe, where the velocities of vast orbs of matter are found accelerated to a speed of more than a thousand miles per minute, and where the velocities of the propagation of mechanical impulses through the subtile medium of electricity are effected with the speed of light from the sun, or at the rate of nearly 12,000,000 miles per minute.

On this principle of mechanical science, it admits of calculation, that, if the exertion of an effective impulse adequate to lifting 1 pound at the rate of velocity of 33,000 feet, or about 6 miles per minute, constitutes the measure of the motive power of a horse, the same force, were it propagated with the velocity of light, or of the gravitating impulses between the sun and the earth, would represent the motive power of 2,000,000 of horses.

This calculation seems to demonstrate the philosophy of the employment of so rapidly moving an agency in the mechanics of nature as that of electricity; whereby apparently feeble impulses are enabled to accomplish vast results.

MEASURES OF FINITE SPACE AND TIME.

The various nations of the earth have adopted different standard measures for denoting certain determinate portions of *space* and *time*.

The standards of finite portions of space are founded upon arbitrary subdivisions, severally adapted for conveniently measuring the dimensions of the surface of the earth, of fields, and of various kinds of bodies and fabrics constituting articles of merchandise. It is somewhat remarkable that the standard measure of length is established by statute law in England upon the basis of the *measure of time* by the vibration of a pendulum;—that is, upon the basis of the perfect uniformity and invariability of the *cause of the natural motive power of gravitation*, which produces the regular swinging of a pendulum.

It having been ascertained by a series of the nicest experiments made in London, that a pendulum placed at the level of the sea must be exactly $39\frac{1393}{10000}$ inches in length to perform a vibration in precisely one second of time, whilst the thermometer indicates a temperature of 60° of Fahrenheit's scale; it has consequently been enacted by Parliament, that recourse shall be had to this test of the measure of space, in case of the loss or destruction of the brass standard measures of the realm.

The least standard measure of time has been very generally fixed at the interval termed a *second*, being $\frac{1}{86400}$ portion of the time occupied by the earth in each daily revolution on its axis. The longest portions or periods of time are recognized by geologists from "the records of stones," deeply buried in the substrata of the earth. It has been computed by geologists, that periods of some hundreds of thousands of years must have elapsed, to allow time for the gradual accumulation of the great alluvial deposits forming the deltas of the principal rivers of this earth, and for the growth of the masses of plants constituting the beds of mineral coal that are now found buried deep beneath its surface.

The most perfect idea we can form of the continuous lapse of time, is by the comparison of it to a flowing river forever advancing toward us, forever passing by, forever receding. These contemplations have led to three relative subdivisions of time,—the advancing *future*, the fleeting *present*, and the irrevocable *past*. We can only realize that we are conscious of the *present*, and that it is ours;—the *past* belongs to history, the *future* to hope.

MATTER.

> "Look downward on that globe, whose hither side
> With light from hence, though but reflected, shines:
> That place is *earth*, the seat of man ——."
>
> MILTON.

OCCUPANCY OF SPACE BY MATTER.

THE first dawning of human intelligence recognizes the occupancy of portions of space by finite objects, having *length*, *breadth*, and *thickness*. These being relative terms, descriptive of the limits of the space occupied by each finite object, they have been philosophically denoted by the term EXTENSION, which is equivalent to the popular term, EXISTENCE.

The fact of the occupancy of space constitutes the most positive test that can be adduced to prove the EXISTENCE OF MATTER.

If any portion of matter had ever ceased to occupy space, it might have been concluded that it had ceased to exist. But as it has never been discovered in a single instance that an atom of matter has ceased to occupy space, the belief has become established that MATTER IS INDESTRUCTIBLE.

Matter never ceases to occupy space on the surface of our earth, although it may apparently do so in some of the changes of its states of existence. Vast structures of wood may, to our eyes, disappear from the earth, as if destroyed, by the conflagration of a city. During the process of fermentation and putrefaction of animal and vegetable bodies, they gradually disappear;

yet not a single atom becomes wasted or lost in the economy of nature. There is merely a change of the form in which they occupy space.

It follows as a necessary consequence of this property of the EXTENSION of matter, that no two atoms or masses can occupy the whole of the same space in the same moment of time. If a body in motion encounter another body fixed immovably at rest, it cannot pass through it and occupy at the same instant all the space occupied by the body at rest without destroying it; which has just been shown to be impossible. Consequently the whole, or the parts of one of the bodies must necessarily be moved aside out of the way of the other, and be thus caused to occupy a different portion of space. If the body at rest be not thus caused to occupy a different portion of space, the body in motion must become turned aside or else arrested in its course. This reciprocal influence constitutes MECHANICAL ACTION and REACTION.

This tenacious occupancy of space by matter has given rise to the philosophical term of—IMPENETRABILITY OF MATTER—a term which the following reasons induce us to consider inapplicable, and therefore properly to be discarded.

It is practically found that every body or mass of atoms is readily *penetrable* and *divisible* by various mechanical and chemical processes. There is thus a palpable discrepancy between this philosophical and the popular meaning of the term, *impenetrable.* The reader is therefore misled by such a false term, or he must be reduced to artificially construing it, as Locke does, "as a negative term, and more a consequence of solidity, than an evidence of solidity itself."*

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* In attempting to reconcile the manifest discrepancy of the philosophical and practical meanings of this term, Dr. Lardner observes, "it will be most clearly explained by defining the positive quality from which it takes its name, and of which it merely signifies the absence." This explanation is truly like the celebrated one of the Latin word "*Lucus, à non lucendo.*"

In all philosophical definitions regard should be had to the established meaning of words; otherwise, as observed by Mr. Watts, in his Treatise on Logic, "an old idea will occur to the mind when a word is heard or read, rather than any new idea we may fasten to it."

The term "*Extension,*" considered as a property of which matter cannot be deprived, is therefore preferable to that of "*Impenetrability,*" as being indicative of its unyielding tenacity of occupancy of space.

EXTENT OF SPACE OCCUPIED BY MATTER, OR QUANTITY OF MATTER.

As the remotest portions of space, discoverable by means of the most improved optical instruments, appear to be sprinkled with stars, each of which is doubtlessly the central sun to systems of worlds like ours, we have reason to believe that *infinite space* must be occupied by an *infinite series of worlds of matter.*

So innumerable, indeed, are these radiant orbs of matter, constituting the remote stars in the firmament, that their commingled radiance becomes blended into a nebulous haze of dim light, denominated by astronomers, *Nebulae*—the Latin word signifying *clouds.* The bright cloud-like appearance in the evening sky, popularly termed the milky-way, consists of these aggregations of stars, or suns. When viewed by powerful telescopes, this nebulous light becomes resolved into such an array of glittering orbs of light, that astronomers, as if at a loss to compute their number, have applied to them the descriptive name of "star dust," in the depths of space.

Although finite intelligences are incapable of comprehending infinite space, as before stated, or the extent of the occupancy of portions of space, by an infinite series of portions of matter, yet it affords an interesting view of the sublime scale on which the "mechanics of nature" are effected in the free space of the heavens around us, and within the immediate scope of our vision, even to attempt to form an estimate of the quantity of matter occupying space in the depths of the heavens.

Although only about 2000 stars have been designated by astronomers by appropriate names, yet the number noted for particular observation is not less, according to Sir John Herschel, than 200,000, " which must all be registered in lists, (so as to be at once referred to, and so that none shall escape,) if not by actual names, at least by some equivalent reference to their relative positions. A correct description of the exact relative positions of the fixed stars, recorded in catalogues, for reference for all future times, supplies the only effectual means we have for ascertaining if they change their places in the lapse of ages." By these recorded observations, and by maps of the heavens, it has been established beyond a doubt, that impulses of mechanical force are exerted between the respective centres of some of the stars, as tested by the observable revolving movements of couples of stars about each other.

By means of these observations, astronomers have estimated that more than 20,000,000 of stars are discoverable in the portion of space included within the range of modern improved telescopes. Supposing all these stars to be suns like that which forms the centre of our system of worlds, we may deem it probable that there are more than 300,000,000 of worlds of matter, each equal to those of our solar system, which occupy the space sufficiently near to our sun, for its rays to become interchangeably reciprocated therewith. These worlds have been claimed by astronomers as belonging to *our cluster in the heavens*, the reciprocal interchange of the radiations of light being deemed a neighborly bond of relationship between these remote systems and our own.

There is no reason for believing that our solar system constitutes a central point, about which are collected this vast cluster of worlds, and that all the space beyond our contracted scope of vision is left unoccupied. On the contrary, there is reason to believe that throughout infinite space, in every direction, are sprinkled similar clusters beyond clusters, like glittering dust diffused throughout space unlimited by verge or shores. The imagination, in this bold exploring excursion, finds no resting-place for terminating its ever onward flight; and, like the dove fluttering over the boundless flood of waters, finally droops its weary wings, to return to this minute terrestrial orb, that becomes almost lost to it amid the vastness of the extent of space, and of countless myriads of surrounding worlds of matter.

The *quantity of matter* contained in some of these brilliant orbs, is as astounding as the number of them. The sun is computed to be composed of a mass of matter a million-fold larger than our earth; and according to the lowest estimate that has been made by Herschel and Bissell, of the diameter of the star Arcturus, its size appears to be thirteen hundred fold greater than that of the sun; whilst, in turn, this star has been estimated to be only $\frac{1}{11}$th part of the size of the brilliant star Sirius. According to these calculations, it therefore appears that this last named orb of matter must be several thousands of millions of times larger than the globe of matter constituting "the seat of man," the mechanism of which we are now engaged in examining.

Whilst these considerations inspire the sublimest conceptions of the infinite power displayed in this wonderful extent of the mechanism of the universe, they afford a salutary lesson to abate human pride. Indeed, this contemplation of the vastness of the number, as well as magnitudes of the worlds of the universe, is almost sufficient to cause an individual of the human species, as suggested by Addison, "to fear that his relative insignificance may cause him to be lost sight of and forgotten amid the vastness of the universe."

THE MINUTE PORTION OF SPACE OCCUPIED BY AN ELEMENTARY ATOM.

If the unlimited extent of the quantity of matter composing the universe excite our astonishment on the one hand, the minuteness of a single elementary atom, on the other hand, may equally excite our wonder. Many distinct individual atoms are supposed by chemists to be grouped together to form a sufficient aggregation of them to become visible even by the aid of a microscope. It is certain that the smallest particle of a grain of sand discernible by the naked eye, becomes developed by the microscope, as if it were a fragment of a rock; whilst the highest powers of the same microscope will barely render perceptible certain minute animalculae, many thousands of which collectively do not exceed the bulk of a single grain of sand. In a cubic foot of water taken from the sea in polar regions, it has been estimated that nearly as many of these living beings exist as there are human beings inhabiting the globe. Every individual has its peculiar members, and circulating fluids therein, each particle of which has the power to occupy space. It has been deemed a test of the most extraordinary perfection to which microscopic instruments have been brought, that the human eye is enabled to discover that there are regular furrows on the surfaces of a species of sea-shell. Every one of these furrows must have been moulded by aggregations of numerous atoms of matter passed through the organs of the sea-fish.

Many very interesting microscopic examinations have been made by Ehrenberg, to discover the forms of the shells of a class of minute animalculae termed "Infusoria." These shells are too small to be seen by the naked eye; and yet the occupant of each one of them must have been a complete animal mechanism, with all the members necessary for performing the functions of vitality.

Ehrenberg states that the smallest square magnitude discernible by the human eye is about $\frac{1}{432}$ part of an inch, or $\frac{1}{36}$ of a *line*. He affirms that there are direct proofs of the existence of atoms no larger than $\frac{1}{10000}$ part of a *line*, or $\frac{1}{120000}$ part of an inch; and still others which can be proved indirectly to be of a less magnitude than $\frac{1}{6000000}$ part of a *line*, or $\frac{1}{72000000}$ part of an inch in diameter. He continues, we are not to harbor the thought of ever attaining the power of discovering the minute individual atoms of matter.

Undiscoverable as these individual atoms of matter may be by any of our powers of perception, yet reason induces us to believe that every such atom does certainly occupy a portion of space of which it cannot be deprived, as we believe in the truth of the axiom of geometry,—one of the most certain of sciences,—that "magnitudes which exactly fill the same space are equal to one another."

The minutest subdivision of space to which human art has yet attained, appears to have been accomplished by the aid of a micrometric screw in marking with the point of a diamond grooved lines on a piece of glass. By this means 56,306 lines have been cut on one inch; and to discover these several marks or lines, has been assigned as the highest standard test of the power of the most perfect microscopes.

As an individual atom of matter occupies so minute a portion of space as to be undiscoverable by human powers of perception, the fact becomes manifest, that every discoverable portion of matter must consist of a grouping of atoms.

The least discoverable portion of matter has been termed a MOLECULE.

A molecule being composed of an aggregation of atoms, really represents the *mechanical static condition* of several elementary atoms,collected and held fastly grouped together by continuously repeated impulses of mechanical force.

As masses are aggregations of atoms, whatever controls the condition of the atoms must control the whole.

Without this continuous *molecular action*, the very rocks and mountains, forming the solid portions of the crust of the earth, would exist as separate individual atoms, diffused invisibly in space; where they might appear to the inhabitants of other planets like the transparent nebulous haze of a comet.

It follows as a necessary consequence of these facts, that the science of mechanics, and all the physical sciences, are based on this continuous molecular action.

Taking into view the fact, that the ultimate atoms of matter are all too minute to become appreciable by human powers of perception, and that a number of atoms must be actually united and held fast together, to constitute a discoverable magnitude or *molecule*, we arrive at a just comprehension of Sir Isaac Newton's definition of MATTER. "Matter is an aggregation of the smallest parts, which are material, and extended, and *by an unknown power* are strongly connected with each other."

This unknown power, as Newton has observed in his treatise on optics, "it is the business of experimental philosophy to find out."

Molecular action, or the propagation of impulses between atoms at insensible distances, constitutes the basis also of chemical science; for, as stated by an eminent chemist, "*combination*, indeed, appears to be the natural condition of matter."

In carrying out a theory of molecular action, Buscovich has even supposed that atoms may be considered as mere centres of forces or powers, and not simply as absolute constituent portions of bodies.

To group a sufficient number of atoms together to form a mass, or molecule, of a magnitude discoverable by human powers of perception, and to sustain them thus aggregated together, there must be exerted a continuous repetition of impulses of mechanical force between such atoms. We hence arrive at a very important truth, or law of natural motive power, which constitutes the basis of the science of the mechanics of nature, viz: that *all human knowledge of the modified forms, and of the characteristic properties of matter, is derived from the continuous and reciprocal propagation of impulses of mechanical force between individual atoms.*

And consequently all human knowledge of the characteristic properties of matter must necessarily be derived from observations of masses, not of single individual atoms;—of the *relative* and not of the *absolute* condition of such atoms. For this reason every theory of the absolute condition of the existence of a unit of matter cannot be otherwise than speculative.

But so far is the preceding fact from being an obstacle to arrest the progress of the science of the nature of atoms too minute to be handled, or even to be separately discoverable, that it may rather be deemed as a part of the design of the Creator, to prolong the pleasure of gaining a knowledge of the details of his wonderful works, by continuous researches founded on synthetical reasonings, adapted for detecting the characteristic properties of the minutest parts, from their relationships to the whole.

The inadequacy of human faculties to take cognizance of individual atoms near at hand, and of the hugest masses at remote distances in the depths of the heavens, serves to call forth the ever-delightful exercise of the intelligence and reasoning powers, which might have remained nearly useless, had man been endowed with perfectly clear-sighted faculties of perception and intuitive knowledge.

The reciprocal action and reaction between atoms produce the result of counterbalanced conditions of a relative state of their rest in fixed or solid states of groupings into the various masses, or bodies, which constitute the crust of the earth. The very fact of the solidity of portions of matter, is a proof of the equal action and reaction of counterbalanced forces, which produce the result of their relative *state of rest* or *natural static condition*, as we shall hereafter denominate all the natural groupings of the elementary atoms, which occupy space around us.

Every change of these groupings of atoms from one natural static condition to another, such as occurs when the steamy vapor of water in thunder-clouds becomes condensed into rain-water, will be considered as developing a resultant action, constituting the *natural dynamic conditions of matter*, as observable in the phenomena of lightning.

We shall first proceed to examine the natural *static* conditions of terrestrial matter, in accordance with the usual classification of mechanical science, and then the natural *dynamic* conditions of such matter.

STATICS OF THE MECHANICS OF NATURE.

NATURAL STATIC CONDITIONS OF GROUPINGS OF ELEMENTARY ATOMS OF TERRESTRIAL MATTER INTO CONSISTENT FORMS.

THE earliest account recorded of the occupancy of space by the matter constituting "the earth—the seat of man," is contained in the Mosaic history of Creation. It is therein stated, that "in the beginning God created the heaven and the earth," which "was without form and void." And God said, "Let there be light, and there was light."—And "God said, Let the earth bring forth grass, the herb yielding seed, and fruit-tree yielding fruit after his kind, whose seed is in itself." After the creation of plants, "God made the beast of the earth after his kind, and cattle after their kind, and every thing that creepeth upon the earth after his kind." And lastly, "God created man."

By this brief ancient historical record of the "creation," it appears that after the matter now constituting this earth was originally caused to occupy space, it was "without form and void,"—a chaos.

On reducing the chaotic mass of matter of the earth to form, when it was originally without form, the first agency called into requisition appears to have been that of "LIGHT," the dynamic action of which, as excited by the sun at the present day, still continues efficiently to cause "the earth to bring forth grass, the herb to yield seed, and the fruit-tree to yield fruit."

All the groupings of elementary atoms, which bear the impress of having been moulded by the organs of plants and animals into vegetable and animal bodies, have been denominated by chemists *Organic Formations;* and all the groupings of atoms of terrestrial matter, which bear no impressions of having been moulded into the mechanisms of vegetable and animal bodies, have been designated as *Inorganic Formations.*

All animal bodies are found to be constituted of re-organizations of vegetable organic formations, in accordance with the original decree, that "to all animals, wherein there is life, I have given every green herb for meat."

The original mechanical groupings of atoms into all kinds of vegetable organic formations, are produced by the action of the sun, modified by the mechanisms of the organs of living plants.

No appropriate term having been introduced into scientific language, to denote the continuous propagation of the dynamic action of the sun to terrestrial matter, and also the continuous propagation of these dynamic impulses by successive actions and reactions between the atoms and masses of such matter at insensible and sensible distances from each other, the term, *electrodynamic action of the sun*, will be used to denote it in this investigation of the sources of natural motive power.

The groupings of atoms steadfastly fixed in solid relative positions, whether of organic or of inorganic formations, found naturally existing on the surface of this planet, will be denoted by the term, *natural static conditions of groupings of such atoms*, as before described, in contradistinction to their unstable groupings into certain temporary organic and inorganic formations, which will be denoted by the term, *constrained static conditions* of the groupings of such atoms.

On taking a general survey of the mechanical properties of the matter constituting the crust of the planet on which we find ourselves existing, we recognize first the facts of the groupings of atoms into two remarkably distinct kinds of natural static conditions of FLUIDS and SOLIDS; the *fluid* air, water, and electricity, composing the former, and the *solid* mineral or earthy matter the latter.

These four subdivisions exhibit truthful representations of the natural static conditions of all terrestrial matter, as viewed by the light of mechanical philosophy, and considered as representing "elements of power."

It will be noticed that this classification includes the "four elements" of the ancient schools of philosophy, supposing "fire" to be represented by electricity. As the science of chemistry was unknown to the ancient philosophers, there are very strong reasons for supposing that their classification of all matter into only four elements, for which they are now frequently derided, was in proper accordance with their principles of mechanical philosophy.

No one, who has followed the acute reasoning displayed by the disciples of the ancient schools of philosophy, can entertain for a moment the belief that those sagacious men did not know the difference between the several kinds of elementary substances, such as the metals, &c. They referred to these kinds of matter as "*substances*," and not as elements, as is manifest by the doctrine, once maintained by a Grecian philosopher, that "all substances are composed of one element."

The natural static conditions of FLUID and SOLID groupings of atoms are real mechanical effects produced by adequate mechanical causes, which it is the task of the science of mechanics,—the science of motion and rest of matter,—to develop.

FLUIDS.

NATURAL STATIC CONDITIONS OF THE GROUPINGS OF ATOMS INTO INORGANIC SPHERICAL FORMATIONS OF FLUIDS.

THE existence of molecules in the freely movable conditions of *fluids*, is abundantly recognizable in the air and water, which surround the solid crust of the earth; and their spherical formations in the globule of the rain-drop and of mercury. Indeed, the mobility of fluids is doubtlessly ascribable to this spherical molecular grouping.

The states of fluidity and solidity of groupings of atoms are in most cases relative, being contingent on the intensity of the electrodynamic action of the sun. The state of fluidity is absolute only in the instances of the few kinds of pure gaseous elementary substances of oxygen and nitrogen, constituting the air of the atmosphere, and hydrogen, constituting one of the elements of water.

These gases, whilst artificially separated from union with other atoms, and in a pure simple state, have never yet been rendered solid, or even liquid, by the most intense reduction of temperature combined with the most intense available pressure; but they are all found not only in liquid, but even in solid conditions, when naturally or artificially reduced to static conditions of groupings with each other in various organic and inorganic formations.

Mechanical science teaches us that to produce the result of the groupings of atoms into a spherical form, there must necessarily be an equal action and reaction between the centres of every atom of the mass.

On the contrary, when fluid spherical groupings of atoms become resolved into solidly fixed arrangements, it is found that there are developed predominating mechanical impulses between particular ends or *poles* of the several approximated atoms, as familiarly observable in the process of the shooting of the spiculae of ice on the surface of pools of freezing water.

These angular arrangements of the grouping of atoms into solid bodies are recognized as the phenomena of CRYSTALLIZATION ; and are consequent on the *polarization* of the atoms of the mass of a crystal.

At the ordinary temperature of the portions of the earth's surface exposed to the average intensity of solar action, the only groupings of atoms into freely movable fluid conditions are those of water and atmospheric air. Hence the grouping of atoms into these two widely diffused fluids may be deemed the only natural static conditions of spherical groupings of atoms.

Although mercury, alcohol, &c., may be deemed an exception to this observation, as they exist also as fluids at the average temperature of the earth's surface, yet it is to be remembered that the natural static condition of mercury is the *solid ore* of cinnabar, in which the atoms are grouped with sulphur and oxygen, and from which they are artificially distilled by the combustion of fuel; as is also the mode of the artificial procurement of alcohol from organic formations. These two fluids, and also numerous other kinds, are to be considered as representing the artificial *constrained static condition* of groupings, instead of a natural static condition.

FLUID INORGANIC FORMATIONS.

Table of the relative proportions of the different kinds of atoms grouped into static conditions of fluid spherical formations, at the average temperature or degree of electrodynamic action of the sun on terrestrial matter.

Natural Fluid, static conditions of,				*Kinds of Atoms.*	
WATER	composed of	8 parts	(by weight)	of oxygen,	INORGANIC SPHERICAL FORMATIONS OF MOLECULES.
	"	1 "	"	" hydrogen,	
		9 "			
AIR	"	22.76 "	"	" oxygen,	
	"	76.15 "	"	" nitrogen,	
	"	1.03 "	"	" vapor of water,	
	"	0.06 "	"	" carbonic acid gas,	
		100.00			
CARBONIC ACID GAS floating in the air,		27.27 "	"	" carbon,	
		72.73 "	"	" oxygen,	
		100.00			
ELECTRICITY	"	Imponderable		electric matter.	

By glancing the eye over the preceding table, it will be noticed that the three fluid groupings of atoms into the natural static conditions of water, air, and carbonic acid gas, are constituted of only *four* kinds of elementary substances, viz., oxygen, hydrogen, nitrogen, and carbon.

These four kinds of elementary atoms play a most interesting and important part in the mechanics of nature, as we shall now proceed to show. Being naturally fluid, and freely movable by the least impulses impressed upon them by the electrodynamic action of the sun, they are constantly fluctuating in CURRENTS of WIND and WATER over the earth's surface, subserving the various purposes of propagating the electrodynamic action of the sun in the modified forms of the natural motive power of the *wind*, *tide*, *water power*, and artificial *steam power*.

These fluid atoms serve also as the appropriate food of plants; which, being rooted to one spot of earth, and incapable of roaming in pursuit of food, like animals, from place to place, must necessarily be supplied with their aliment on the spot where they grow. They have no chance of obtaining any soluble atoms of food, except those wafted to them by the passing breeze and falling shower; and hence, in the economy of nature, the functions of their mechanisms are all systematically adapted to collecting the four preceding kinds of fluid elementary atoms, and to passing them through their appropriate organs, to become incorporated into the solid *organic formations* of roots, stems, leaves, fruits, grains, and seeds of all kinds of plants.

This transformation of *fluid* carbonic acid gas and water into *solid* states, can only be effected by the organs of living plants, whilst they are excited by the electrodynamic action of the sun. It may hence be concluded, that the organs of plants serve rather to modify the directions of the propagation of the electrodynamic impulses of the sun, to produce the groupings of atoms into the preceding solid organic formations, than to originate the mechanical impulses that produce vegetable organic formations; for the life power of plants remains dormant until excited by solar influences.

In this point of view, the organs of plants may be considered as mechanisms determined by the will of the Creator to modify the electrodynamic action of the sun, to produce certain specific kinds of groupings of atoms, as the ingenuity of man, on a humble scale, may determine the direction of the propagation of the same electrodynamic action through the mechanism of a thermoelectric apparatus, to produce the arrangement of atoms into inorganic formations of crystals.

From the remarkable fact that the four preceding kinds of atoms, oxygen, hydrogen, carbon, and nitrogen, are appropriated as the food of plants, to become metamorphosed by their organs, whilst subjected to the electrodynamic action of the sun, into the organic formations of wood, peat, &c., constituting *fuel*, and into grasses, fruits, grains and seeds, constituting *food*, adapted to become reorganized into animal bodies, these four kinds of elementary substances are denominated by chemists, "ORGANIC ELEMENTS."

From the above stated fact of the reduction of the organic elements into fuel and food by the electrodynamic action of the sun, it is manifest that the originating cause of *steam power*, producible by the combustion of fuel in the furnace of the steam engine, and of *animal motive power*, producible by the combustion of food in the lungs of animals, are alike traceable to the originating cause of the propagation of the electrodynamic action of the sun to the mechanisms of the organs of living plants.

The elucidation of these principles will occupy our attention in the investigations that will presently be followed out, when we come to treat of organic and inorganic actions and reactions.

INORGANIC FORMATIONS.

FLUID MOLECULES OF WATER REDUCIBLE FROM THEIR NATURAL STATIC CONDITIONS TO THE CONSTRAINED STATIC CONDITIONS OF VAPOR, OR STEAM, BY THE ELECTRO-DYNAMIC ACTION OF THE SUN.

So gently and quietly is the electro-dynamic action of the sun propagated upon the surface of our planet, that few human beings are aware of the vast extent of actual physical force thereby developed during a bright, calm summer's day, when every visible object remains still, and even the aspen-leaf ceases to quiver and droops motionlessly on its slender stem. To realize the extent of the propagation of the electro-dynamic action of the sun thus effected, requires recourse to mathematical calculations.

Supposing the evaporation of water by solar action on a limited belt of the earth's surface, comprised within the tropical regions alone, to be only one-eighth of an inch daily, and that this water, in the constrained static condition of vapory clouds, becomes elevated to the average height of 5,000 feet in the sky, effective impulses are thus continuously developed, which exceed 4,700,000,000 *horse-power;* an extent of motive power one hundred and thirty fold greater than that of the muscular energies of all the active human population of the earth, estimating the number at 250 millions of vigorous people.

All this mechanical power is every day exerted to irrigate the surface of the earth, and to facilitate the groupings of atoms into vegetable organic formations.

This calculation may afford some slight idea of the extent of the impulses of mechanical force propagated between the molecules of water, to reduce them from their natural static condition of grouping, to the constrained static condition of aeriform vapor, or *steam.*

The molecules of water are thus shown to be designedly adapted to receiving and propagating continuously the electrodynamic action of the sun in the modified form of mechanical impulses, which cause these molecules to become separated from each other, until they occupy, in the form of vapor, about seventeen hundred fold more space than they occupied in the form of water; expelling an equal volume of atmospheric air from adjacent space, and against a positive reaction of about 15 lbs. on each square inch of the surface exposed.

In this state of diffusion, the molecules of water occupy more space than those of the surrounding atmosphere; and being thus specifically lighter, they become buoyed up to float in the upper regions of the atmosphere.

The atmospheric air, excluded from the enlarged space occupied by the steamy vapor, unceasingly reacts thereon with the above stated specific force of 15 pounds pressure to each square inch of the surface exposed; and were there not continuously excited an equivalent reaction of the vapory molecules of water, the air would rush back unresisted, to reoccupy the space from which it had been ejected.

Observation teaches us, that this result of the recoil of the air does finally take place. After the molecules of vaporized water have remained for a longer or shorter time in their constrained static condition of grouping as vapors, they are familiarly known to become suddenly changed from their constrained static condition of steamy thunder-clouds, to drops of rain-water, occupying only $\frac{1}{1700}$ part of the space previously occupied by the same atoms, developing during their change from one static condition to another violent dynamic action in the modified form of a flash of lightning, with the attendant phenomena of light, of heat, and impulses of mechanical force, in the bodies traversed by it. This is one of the most common cases of the production of fluid inorganic formations by the propagation of the electrodynamic action of the sun to terrestrial matter.

The preceding example of the subserviency of the fluid medium of water, spread out to cover nearly three-fourths of the earth's surface, and consequently to receive three-fourths of the electrodynamic action of the sun propagated to this planet, has been adduced for the special purpose of serving as a type of the constrained static conditions of groupings of atoms of other kinds of elementary substances into organic formations of *fuel* and *food*; from which such groupings are prone to recoil, under favorable contingent circumstances of proximity of other atoms, to their original natural static condition of carbonic acid gas and water, like the vapor of thunder-clouds recoiling to drops of rain-water, developing electrodynamic action in the change from one static condition to another, in the variously modified forms of electricity, heat, light, and impulses of mechanical force, as before recapitulated.

With this view of the functions of the atoms of the fluid oceans, we can no longer call them "a wide waste of waters;" for truly the oceans serve as the great exciting galvanic troughs for receiving and propagating the electrodynamic action of the sun, producing the result of rarefying and transporting water for the irrigation of the neighboring continents, and for becoming incorporated into the living bodies of vegetable and animal organic formations. An attentive observer of the plans of the Mechanics of Nature finds no "waste" in the economy of the arrangement of any part. Even the sandy deserts of Africa are in this sense no "waste;" for they subserve the purpose of receiving the electrodynamic action of the sun for producing partial rarefactions of the earth's atmosphere, and consequent determinate currents of cold air from wintry northern regions to this central focus, or hearth of the earth, to become there warmed and returned in counter currents of air in the upper atmosphere. The electro-dynamic excitation of the sun is thus diffused toward the polar regions of the adjacent continent of Europe. A similar current of warm water of the Gulf Stream is more palpably found sweeping onward toward the British isles and the shores of western Europe, thus propagating to them the electrodynamic action of the sun incident on the oceans situated beneath the equator, and rendering habitable the mountains of Norway and Sweden. In parallels of latitude of western Europe, which are affected by intense frosts on the American continent, are cherished the olive, the fig, and the orange.

The propagation of the electrodynamic action of the sun is thus diffused through the medium of fluid water and air, to quicken vegetable life on the great continents, and to produce vegetable organic formations of food and fuel.

In these instances there are exhibited before us, in bold relief, the functions of the fluid subtile matter of electricity as the medium for receiving and sustaining the impulses of mechanical force. These produce the *static* conditions of the groupings of atoms into various inorganic and organic formations, and the resultant *dynamic* action developed in variously modified ways on every change of such groupings from one static condition to another.

FLUID ELECTRIC MATTER CONSIDERED AS ADAPTED TO PROPAGATING IMPULSES OF MECHANICAL FORCE FROM THE SUN TO THE EARTH, AND BETWEEN THE CENTRES OF ATOMS AND MASSES OF TERRESTRIAL MATTER.

> "Let down our golden, everlasting chain
> Whose strong embrace holds heaven, and earth, and main."
> ILIAD, BOOK VIII.

The phenomena of flashes of *lightning*, sometimes appearing like the glittering links of a dazzling chain suspended from imminent black thunder-clouds in the sky, have attracted the attention of mankind from the earliest records of history. Lightning was once regarded with religious awe and reverence by an enlightened people, and was considered as an immediate revelation of the power of the king of the heathen gods. Jupiter is usually represented in ancient mythology as seated on clouds, and brandishing thunderbolts in his right hand. As beautifully observed by a French philosopher, it remained for our illustrious countryman, Franklin, "to wrest the thunderbolt from heaven, as well as the sceptre from tyrants," and to reduce the lightning to a plaything to be experimented upon in the hands of scientific men.

The gradual progress of discovery has recently imparted the greatest interest to the study of the modes of propagating impulses of mechanical force through the medium of electric matter, with extreme rapidity, to remote distances; and of exciting and sustaining the continuous propagation of impulses of mechanical force between the centres of atoms at insensible distances, as practised in the now common use of electromotive power for telegraphic purposes, and for accomplishing processes of electro-metallurgy. The recently discovered motive powers of electro-magnetic machines have also added fresh interest to the study of this new branch of science, denominated ELECTRO-DYNAMICS.

This term is derived from the original Greek word denoting, *amber*,—ELECTRON, and DUNAMIS, signifying *power*,—amber having been the substance first subjected to friction by the ancient philosophers to develope most effectively a motive power adequate to attracting feathers, straws, &c., held near it.

The recent progress of the science of electrodynamics has invested the once deemed fanciful imaginings of the ever admirable Greek poet, Homer, with the appearance of a philosophical truth, demonstrating the fact that electrodynamic action, as propagated from the sun, does really constitute the "everlasting chain, whose strong embrace holds heaven, and earth, and main," by reducing all elementary atoms into constrained static conditions of fluid and solid inorganic and organic formations.

The preceding phenomena impressively introduce to our knowledge the existence of a subtile FLUID MEDIUM OF ELECTRIC MATTER, pervading all space not occupied by other matter, and serving to propagate impulses of mechanical force between portions of terrestrial matter, whether at sensible or insensible distances.

In referring to the violent disruptive propagation of electrodynamic action from the condensing vapor of water of thunder-clouds in the sky, this peculiar phenomenon has received the appropriate name of "Lightning." In referring to the more quiet propagation of the same electrodynamic action in other modified forms between atoms and masses of terrestrial matter, the phenomena are commonly ascribed to "electrical attraction" and "repulsion."

The positive fact that impulses of mechanical force are propagated through the medium of fluid electric matter from the sun to the earth, has been demonstrated by the phenomena of the reduction of molecules of water from their natural static condition to the constrained static condition of steamy vapor. The continuous propagation of the solar action, in the modified form of impulses of mechanical force, has also been referred to, as developed by the dynamic impulses resulting from the recoil of the steamy vapors in the sky to their natural static condition of water. To illustrate still more palpably the details of the continuous propagation of impulses of mechanical force through the medium of electric matter, so as to present practically the several phenomena recognizable by sentient beings as the effects of the action of electricity, heat, light, and mechanical impulses, some further preliminary details will be adduced.

As the steamy vapors reduced to the constrained static condition of thunder-clouds are beyond the reach and control of man for experimental purposes, recourse must necessarily be had to artificial expedients for obtaining the more immediate control of similar steamy vapors.

The direct electro-dynamic action of the sun admits of being concentrated by convex lenses and concave mirrors upon the focus of a steamboiler containing water, as it is narrated in history that Archimedes attempted to set fire to a hostile fleet in the harbor of Syracuse.

By means of this expedient, the direct electrodynamic action of the sun admits of being propagated to the water confined within the iron embrace of a steamboiler, to reduce the molecules from their natural static condition of *water* to the constrained static condition of *steam.*

The counterbalanced impulses of mechanical force exerted by the steam constrained within a steamboiler are identically the same, whether propagated by the direct action of the sun as above suggested, or by the indirect action of the sun as effected through the intermediate agency of the combustion of vegetable organic formations of *fuel*, originating from the action of the sun on the organs of living plants. We shall hereafter consider the molecules of water in the condition of STEAM as representing the constrained static condition of counterbalanced impulses originating from the sun, and held like a bended spring in this constrained static condition, ready to propagate energetic impulses.

The usual mode of reducing the molecules of water from their natural static conditions to the temporary constrained static conditions of steam is by means of the combustion of fuel, instead of the awkward expedient of employing the immediate electrodynamic action of the sun as above described. The use of fuel is, philosophically speaking, only a more ready and convenient employment of the propagation of th e same electro-dynamic action of the sun in an indirect form; for it will be presently shown that wood, peat, and mineral coal, constituting fuel, truly represent groupings of atoms of fluid carbonic acid gas and water reduced by the electrodynamic action of the sun on the organs of plants from their natural static fluid conditions, floating in the atmosphere, to solid constrained static conditions of organic formations. On the recoil of these groupings of atoms from the constrained static conditions of fuel during the process of combustion, as on the recoil of the vapory thunder-clouds, the original electrodynamic action impressed upon these groupings of fluid atoms through the mechanism of the organs of living plants on the sunny hillside, again becomes propagated therefrom to the molecules of water in the boiler.

Every steam-boiler, with this simple explanation, becomes recognized in its true character, as a real *electrical machine*, adapted for propagating the electrodynamic action originating from the sun.

Indeed, small steam-boilers have recently been introduced into the lecture-room, as the most effective kind of electrical machine, one of these steam-boilers having proved adequate to exciting "sevenfold more electricity than has been excited by the most powerful frictional electrical machine that has ever yet been constructed."

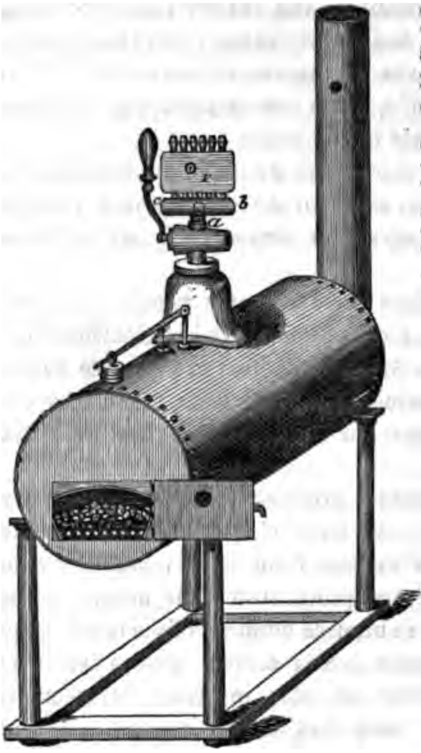
It is only necessary to open a stopcock to allow the vapory molecules of water to issue in the form of a jet of steam into the open air, and thus suddenly to pass from their temporary constrained static conditions of groupings, into their natural static conditions of drops of water, in humble mimicry of the condensing vapors of thunder-clouds, when similar electric flashes are developed with sufficient intensity to dart in vivid coruscations through a space of nearly two feet of air toward adjacent bodies.

One of these steam-boilers, used as an electrical machine, scientifically denominated an *hydro-electrical machine*, is exhibited in the figure.

The stop-cock is shown at C; the boiler is mounted on stout glass legs, to insulate it, and has several small discharge pipes, for allowing fine jets of steam to escape into the open air, as shown at F.

The boiler becomes electrically excited, and also any adjacent insulated bodies against which the jets of steam are caused to impinge. By simply holding the sharp points of a pronged iron rod, resembling a lightning rod, near the jet of steam escaping from any boiler of a steam-engine, working with a pressure of

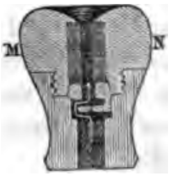
60 or 70 pounds on the square inch of the safety valve, whilst the operator stands on a board resting on strong glass bottles, electric sparks may be drawn from all parts of his body, by persons standing on the ground, and applying their fingers to touch him. Even the insulation of the folds of a warm dry silk handkerchief, wrapped around a pointed wire held in the hand, is sufficient to exhibit electric sparks.



The excitation in these experiments has been ascribed by Professor Faraday to the friction of the globules of water against the sides of the orifice of the discharge pipe of the boiler. With the greatest deference to the high authority of this sagacious experimenter, the following explanations are offered to sustain the principle of the development of electro-dynamic action on every change of the groupings of atoms from one static condition to another.

The mechanical action of the friction of the steam against the sides of the orifice of the discharge pipe, like every other kind of mechanical action of friction, doubtlessly serves to propagate electric excitation; but that all the electrical excitation developed by the hydro-electrical machine is ascribable to the mechanical friction thereby produced, appears improbable. The fact is positively known by the repeated experiments made by Lavoisier, Laplace, Volta, and Sausure, that electrical action becomes developed both during the evaporation, and during the condensation of steam; as exhibited by throwing pieces of red hot iron, and glowing coals, into a vessel of water, and by receiving the condensing vapor on bodies suspended above it. In these cases *no friction* of the globules of water can be imagined to take place, to develope electric action on the diverging gold leaves of the electroscopes suspended from the insulated vessels of water, and from the insulated cold condensing bodies employed in these experiments.

When the change of the grouping of atoms takes place externally to the boiler, by the condensation of the steam in the open air, it is manifest that the electro-dynamic action must become mostly propagated externally to the boiler, and to the surrounding atmosphere. In the practical use of the steam-boiler, as an electrical machine, it has been found advantageous to arrange a contracted aperture, as exhibited in the annexed figure, to *increase the friction*, as professor Faraday suggests, for the purpose of increasing the electrical excitation therefrom.



A piece of non-conducting wood is inserted at M N, which serves to prevent the electrodynamic reaction from counterbalancing and neutralizing the electrodynamic action.

In accordance with the principle of the development of electrodynamic action on every change of the groupings of atoms, from one static condition to another, if the change take place where the impulses become diffused, and directed to counterbalance each other by means of intervening conducting bodies, the resultant action must be correspondingly less manifest. By arranging a line of receiving points insulated from the boiler, the action and reaction of the two oppositely directed impulses are separately and simultaneously discoverable.

This very interesting discovery of the propagation of electrodynamic action from a steam-boiler was accidentally made a few years ago by an engineer, when insulated on a ladder, with one hand partly exposed to the jet of steam escaping from a leak in a steam-boiler, when with the other hand he attempted to adjust the safety valve. An electrical shock followed every attempt to touch the metallic connections with the boiler. This fact astonished him, and led to further investigations, which have disclosed the wonder-working agency of steam as being due to the propagations of electrodynamic action.

Were it practicable to interpose properly arranged non-conducting materials in connection with the boilers and condensers of steam-engines, to prevent the continuous latent propagation therefrom of the electrodynamic impulses, a large steam-engine would become so formidable an electrical machine, that, like a torpedo, it might excite terror in the shocked engineer who might apply his hand to touch the parts of it, and reverberating sounds of disruptive discharges, like those of a thunder-storm, might be heard.

It has long been noticed that lightning appears darting about in the atmosphere above the summits of volcanoes, whilst an eruption is taking place therefrom. As the discharges from volcanoes usually contain vast quantities of steamy vapors, to the condensation of this steam aloft in the cold dry air, and beyond the reach of adjacent conductors, we may probably attribute the excitation of the electricity set free on a great scale, in the same manner as from the steam escaping from the valve of the steam-boiler.

Having repeated the experiment of developing electricity by means of the discharge of steam from a high-pressure boiler, whilst the temperature of the atmosphere was at zero of Fahrenheit's scale, I found that the pointed wires received and propagated the electric action freely, even when held at a distance beyond the actual range of the jet of condensing steam.

This last fact is fraught with instructive information, as conclusively demonstrating that the electrodynamic action does not cease to become propagated from the condensing vapors of clouds in the sky, even when no perceptible flashes of lightning are visible; for the diffusion of their action is thus shown to be taking place quietly, and undiscoverably, except by critical philosophical observations, during the drizzling rain-storm, as well as during the noisy peals and dazzling coruscations of the thunder-storm. Indeed, it is commonly found that telegraphic wires often become the most intensely excited by atmospheric influences during drizzling storms.

In the void space of the upper regions of the atmosphere, where the steamy vapors of clouds are changed from their constrained static condition of grouping of atoms to their natural static condition of water, the electro-dynamic action becomes propagated to the surrounding air in the modified form of electric action in currents, instead of the vibrating action recognizable as that of *heat.* This result is a necessary consequence of the absence of a dense resisting medium, it being manifestly as impossible that there should be producible a vibrating movement of matter, exhibiting the phenomena of heat, where there is no dense matter to vibrate, as that there should be a mechanical action without something to be acted against.

This fact becomes apparent whenever any partially condensed groupings of molecules of water in the form of clouds exist in the upper regions of the atmosphere. The electro-dynamic action of the sun is propagated to them to sustain their constrained static condition of vapor, producing there the excitation popularly ascribed to the "heat of the sun." The electro-dynamic action of the sun being thus propagated to the clouds of vapor that overspread at times the earth's surface, and being there arrested by the reaction necessary to sustain the constrained static condition of the groupings of atoms of vapor, ceases to be propagated further to the surface of the earth. The diminution of this vibratory action produces a sensation recognizable as that of a diminution of heat.

And when, again, these clouds of steamy vapor become condensed into rain-drops in the lofty regions of the air, no surrounding matter being at hand to receive the vibratory action in the modified form of heat, the further propagation of the electro-dynamic action is expended in visible "disruptive discharges of lightning;" or else in invisible electric currents and diffusions, such as quietly reached the pointed wires held near the jet of condensing steam in the preceding experiment with the steam-boiler.

The very fact of the diminution of the vibratory action constituting the "increase of cold" progressively felt on ascending mountains, until a point of perpetual congelation is reached, even under an equatorial sun, is an evidence of this modified form of the propagation of electro-dynamic action in latent electric currents, or by diffused action and reactions of surrounding electric matter only, instead of being propagated in the modified form of heat.

The hitherto unaccountable result of the *cooling of the air* by thunder-storms, when a great quantity of steamy vapor is condensed, and when a great increase of heat of surrounding bodies might theoretically be anticipated, (as when steam is condensed on cold bodies,) admits thus of a rational explanation, as does also the appearance of icy crystals of hail on the very sudden condensation of steamy vapors in the sky, when drops of hot water might be expected to descend from the clouds, instead of crystals of ice.

That electro-dynamic action is convertible into ordinary impulses of mechanical force, and, *vice versa*, that ordinary impulses of mechanical force are convertible into electro-dynamic action, is susceptible of perfect demonstration. By employing the impulses propagated by the piston of a steam engine to turn the cylinder of a common electrical machine, or the wheel of a magneto-electrical machine (which will be presently described), the *mechanical impulses*, in the modified form of steam power, become again propagated in the form of *electrical impulses*. These may be made to produce the phenomena of electric sparks and shocks, or to become again propagated through a far extended telegraphic wire, in the form of *mechanical impulses*, adequate to working the apparatus of an electric telegraph at the distance of many miles from the acting piston of the steam engine.

It admits also of the most conclusive demonstration, that the impulses of mechanical force, thus propagated through the agency of the mechanism of a steam-engine, may be caused at the pleasure of the scientific operator to disturb the electric matter existing in a static condition in connection with the wire coils of the magneto-electric machine, so as to propagate electro-dynamic action to the several material nerves of sentient beings, to produce the phenomena popularly ascribed to the action of "light," of "heat," of "electricity," and of involuntary spasmodic muscular contraction, constituting "animal motive-power." The same mechanical impulses of the steam-engine are also now practically applied in the work-shops of Birmingham, to produce "chemical decompositions," and the establishment of the phenomena of "cohesion" of atoms of solid metals by the process of electro-plating silvered wares.

To demonstrate these results, it is only necessary to employ a fine conducting wire to propagate the powerful electro-dynamic action from a magneto-electrical machine turned by a steam-engine, to produce most intense vibrations of the electric matter, and of the atoms of the wire serving to propagate it, so as to render the wire "red hot," and to produce a perception of colors. In this state of electro-dynamic excitation, the wire is capable of propagating impulses to the material nerves of the eye, recognizable by the tribunal of human intelligence located in the brain, as a simultaneous sensation of LIGHT, and also of a RED COLOR.

By holding this piece of fine wire between the thumb and finger at the commencement of the operation, the incipient vibrations of the atoms of electric and of metallic matter affect the nerves in proximity thereto with a thrilling sensation, recognizable, first, as that of "warmth," then of "heat," then of "burning heat," which is simply an electro-chemical recoil of the organic formation of the muscles, from their constrained static conditions of groupings, to the natural static condition of grouping of carbonic acid gas, and water.

The impulses of mechanical force, propagated as above stated, through the mechanism of a steam-engine, and modified by that of a magneto-electrical machine, may be also employed to produce the electro-chemical decomposition of water, and to change the grouping of the atoms from their natural static condition of a liquid, to that of two distinct kinds of air, or gases—pure hydrogen, and pure oxygen.

In this separate constrained state of existence, the groupings of the atoms of the pure hydrogen represent the constrained static condition of existence of the vapor of thunder-clouds in the sky,—of steam in the boiler,—of organic formations of fuel and food. Under favorable circumstances of the presence of atoms of oxygen and of a little incipient electro-dynamic excitation, applied in the form of a kindling electric spark, the atoms of hydrogen are found to recoil, like a constrained spring, to their natural static condition of grouping with the atoms of oxygen, reconstituting water. They exhibit, during their change from one static condition to another, the phenomena of combustion, and the dynamic action popularly ascribed to "heat" and "light," the two distinct chemical "Imponderable Agents."

Indeed, this hydrogen gas may be burnt as exciting *fuel* beneath the boiler of the very steam-engine that has developed the impulses employed to separate the atoms of hydrogen from their natural static condition of grouping with those of the oxygen, constituting the compound substance of water; and thus a renewal of the same modifications of propagation of mechanical impulses may be effected.

Steam power, through the modifying agency of a magneto-electrical machine, may also be caused, at the pleasure of the scientific operator, to become developed in the modified form of the mechanical impulses of "attraction," "repulsion," and "polarity," popularly ascribed to "magnetism," by simply varying the relative directions of the electro-dynamic impulses propagated through the medium of two approximated conducting bodies, as will presently be demonstrated.

And, finally, steam power admits of being propagated as a mechanical cause of "animal motive-power" through the modifying agency of a magneto-electrical machine, by connecting a conducting wire with the nerves of living, or of recently killed animal bodies, as tested by resulting involuntary muscular contractions of the most violent kind.

This continuous propagation of the electro-dynamic action originating from solar excitation, admits of being thus traced out almost infinitely in variously modified successive static and dynamic conditions of the groupings of atoms. By following out these analogies, it appears that an impulse of mechanical force, when once propagated from the sun to terrestrial matter, must go on forever, by a successive series of actions, and counterbalanced reactions, propagated through the medium of the perfectly mobile electric matter;—and that every such impulse of mechanical force is as indestructible as the very atoms of matter that serve passively to receive and transmit it.

The preceding continuous propagations, through the medium of electric matter, of the successively modified impulses of mechanical force,—first, of *steam power*, then of *electricity*, then of *heat*, of *light*, *cohesion*, *chemical action*, *magnetic action*, and *animal motive-power*, cannot fail of inducing us to regard electrical matter as the sole medium of the propagation of impulses of mechanical force between all elementary atoms and masses of matter, and as maintaining even the fixed rigidity of the component parts of all machines employed to propagate mechanical impulses, as well as serving to propagate motive-power through the modifying agency of such machines.

But the most important philosophical conclusion deducible from the preceding brief array of facts, is the beautiful simplicity of the system of Natural Mechanics, which enables us to dispense with the supposition of the existence of more than half a dozen different "agents of nature."

It has been shown in the preceding examples that the continuous propagation of the electro-dynamic action originating from the sun is adequate to developing between atoms and masses of terrestrial matter all the phenomena popularly ascribed to the preceding agencies. It never having yet been discovered in the economy of Nature, that two distinct causes are employed to produce the same effect, we may with confidence turn our eyes to regard the sun as the prime modifying mechanical cause of all the phenomena of the relative states of motion and rest of terrestrial matter, as it manifestly is of the relative movements around it, as a common centre, of the whole mass of our earth, and of the masses of all the other planets.

The great fundamental law of Mechanics, that "matter at rest cannot put itself in motion," is hereby preserved unviolated by the assumption of the existence of "inherent" and "innate" forces in matter,—an assumption which is now extended throughout every popular treatise on the physical sciences. We are thus left impressed with a clear and distinct idea of the endowment, by the Creator, of each kind of elementary atoms with a systematic grade of powers of modifying the continuous propagation of this electro-dynamic action and re-action between their respective centres—not of self-originating it; precisely as we can clearly conceive of the endowment of the four kinds of atoms of the organic elements with the germinating principle of life-power. They are similarly capable of *modifying*, not of *self-originating* the impulses of mechanical force, which produce the groupings of these atoms into vegetable organic formations. Even animal motive-power is known to be very exactly contingent, in the extent of its development, on the quantity of atoms of food which become changed by combustion in the lungs of animals from the constrained static conditions or groupings of organic formations, to their natural static conditions of carbonic acid gas and water.

These considerations lead us to believe, that in the mechanics of Nature, every effect of the state of rest and motion of matter is produced by an adequate mechanical cause. It is the appropriate province of the science of Mechanics to trace these mechanical effects to their originating mechanical causes, until the final Cause is arrived at, which cannot be mechanical, in accordance with the very law of the science itself, which establishes that "matter cannot move itself."

It has never been duly considered, that the effect of electrical excitation developed even by a common frictional electrical machine is traceable to the electro-dynamic action of the sun on the organs of plants, whereby the atoms of carbonic acid gas and water are reduced to the constrained static condition of the food, which is necessarily burnt in the lungs to propagate impulses to the human hand, whilst applied to turn the crank-handle of the cylinder.

Neither has it been duly taken into consideration, in the excitation of galvanic electricity by the chemical decomposition of zinc, that this substance is artificially reduced to its constrained static condition of a pure metal, from its natural static condition of an ore, by an extraordinary preliminary electro-dynamic excitation in the smelting furnace, wherein ten tons of coal are burnt to produce only one ton of *pure* metal. Consequently an extraordinary extent of electro-dynamic action originally propagated from the sun to produce the groupings of the atoms of the fuel burnt in the smelting furnace, has been again propagated to reduce the atoms of zinc to a pure, glittering mass of metal, as an article of commerce. In this constrained static condition, the pure metal, zinc, represents the similar constrained static condition of the atom of the pure hydrogen—of the vapory thunder-cloud—of the steam—of the food, and fuel, &c., which have just been severally noticed.

Thus we trace, philosophically, the excitation of electricity, both by the common electrical machine and by the galvanic battery, to the sun, as the originating source of the propagation of the impulses of the mechanical force thereby developed.

From the extraordinary facility with which the four particular kinds of atoms of the fluid organic elements receive, modify, and propagate to other kinds of atoms, the electro-dynamic impulses originating from the sun, it might be theoretically anticipated that they are destined to undergo incessant transitions from one static condition of grouping to another.

Readily movable by the least mechanical impulse as they undoubtedly are, yet when we come to compare their susceptibility to receiving, modifying, and propagating the slightest impulses of mechanical force with the perfect mobility of the last named fluid element, electric matter, which serves to appreciate even the movements of one body near another without the necessity of contact, the difference of fluidity appears almost infinite. Indeed the fluidity, or readiness to yield to the least force impressed upon the grosser organic elements, appears to be traceable directly to the presence of the electric matter which surrounds every atom of the groupings of them, and serves to propagate and sustain the mechanical impulses that collect and group these several atoms into molecules, of a magnitude sufficiently great to be discoverable by human powers of perception, as before stated.

The existence of electric matter, in this synthetical view of the relative states of motion and rest of terrestrial matter—of the statics and dynamics of the mechanics of nature—becomes thus brought before us, as specially designed to subserve the purpose of a perfectly mobile, all-pervading fluid medium adapted for propagating the slightest impulses of mechanical force.

The passive attribute of *perfect mobility* renders the fact manifest, that the function of electric matter is specially designed for receiving and propagating the mechanical action, which has been repeatedly referred to under the term "electro-dynamic."

With this explanation, therefore, the term "electro-dynamic" is not to be understood as inferring a self-originating or self-motive power in electric matter; but, on the contrary, in consistency with the established laws of mechanics, merely a passive faculty of receiving and propagating impulses imparted to it through the medium of other sixty kinds of atoms of elementary matter.

The idea of perfect mobility, or readiness to yield to the slightest force impressed, carries with it the idea of the perfect passiveness of electric matter. Our observations of the occupancy of space by the grosser kinds of elementary atoms do not convince us that they exhibit evidences of less ready passiveness, from their resistance to being freely moved in space. For this less ready passiveness is only apparent—all matter being considered as positively passive; and the difference in yielding to forces impressed must be ascribed to the aggregation of atoms into grosser molecules, or masses, through the mechanical action continously propagated by the perfectly mobile electric matter, producing the relative static and dynamic conditions of terrestrial matter, which it is our present purpose to trace out.

The preceding trains of facts, with the reasonings and deductions drawn therefrom, are to be considered, in this preliminary stage of our inquiry, as synthetical hypotheses, assumed to explain classes of facts of the phenomena of the static and dynamic conditions of terrestrial matter; and as trustworthy no further than they may each be independently established by the analytical investigations contained in the following pages.

ELECTRICAL MATTER CONSIDERED AS THE MEDIUM OF THE PROPAGATION OF MECHANICAL IMPULSES FROM THE SUN TO TERRESTRIAL MATTER, AND BETWEEN ATOMS AND MASSES OF TERRESTRIAL MATTER, CONSTITUTING THE INORGANIC ACTION DENOMINATED ELECTRO-DYNAMIC.

It has been previously stated, that the ultimate atoms of every one of the gross material elementary substances are too minute to be discoverable by human powers of perception; and that all human knowledge of the characteristic properties of matter is founded on the continuous propagation of impulses of mechanical force between the centres of atoms, whereby a number of them are grouped together into a mass of sufficient magnitude to become discernible. Of the absolute nature of the individual atoms of all the different kinds of elementary substances we are necessarily ignorant, human faculties being inadequate to taking cognizance of any single individual atom. According to the opinion of microscopists, we must continue to remain profoundly ignorant, unless the present state of the art of constructing optical instruments be very greatly improved.

In affirming that we are profoundly ignorant of the nature of the subtile matter constituting the electric medium, which is diffused throughout all space, we therefore affirm no more than is asserted in regard to all other matter. Even the grosser atmosphere, by which we are surrounded, was not discovered until recently in the history of science, to be ponderable, and to be capable of exerting a pressure on all bodies, although the human body sustains a continuous pressure therefrom, equal to that of the weight of several tons; whilst to cover up this ignorance, it was assumed that the rise of water in a common pump, now demonstrated to be a result of atmospheric pressure, was owing to the "abhorrence of nature to a vacuum."

There is a similar ignorance, probably, still existing in relation to the facts of the actual pressure of an *universal electric atmosphere pervading all space.*

It really seems to be now quite as gross an attempt to conceal ignorance by ascribing the tenacity, or strength of a bar of iron of an inch square to lift a weight of 30 tons, to a supposititious agency, fancifully named "COHESION," as it once was to ascribe the ascent of water in the void space of a pump-bore to the height of 30 feet, to the fanciful supposition of "the abhorrence of nature to a vacuum."

There was an adequate mechanical cause for the ascent of the water to the height of the precise number of feet; and there doubtlessly is an equally adequate mechanical cause for the union of the atoms of a bar of iron, of the dimensions of an inch square, with a force appreciable by the weight of 30 tons, required to pull them asunder.

More peculiarly embarrassing difficulties attend the investigation of the science of the motive power of electricity, than of any other branch of physical science, from the subtile nature of the electric matter; and more particularly from the fact of its universal diffusion, not only as an atmosphere environing each atom of terrestrial matter, but also as extended to all the celestial orbs of matter, including them in a mechanically connected relationship. With the perfect mobility, or readiness of electric matter to yield to the slightest impulses of mechanical action, and to propagate them continuously, it becomes difficult to discover whether electrodynamic action be propagated by means of hydrostatic pressure, by direct momentum, by vibratory impulses, or by all of these modes variously combined, governed by laws as yet undiscovered by human intelligence.

Deeming electrical matter to be like all other matter, we can form no other conception of the nature of the mechanical impulses, which it serves passively to propagate, than of the nature of any other mechanical impulses propagated by one portion of matter to another. An impulse of mechanical force can be nothing more nor less than an impulse of mechanical force, from whatever source originating, and by whatever cause modified.

However the modes of propagating impulses of mechanical force through the medium of electric matter may be practically effected, *mechanical action* remains still an unmistakable test, and indeed the only acknowledged standard test, adopted by the science of electrodynamics; and having no other test standard to refer to, it must be conclusive to human comprehension in all our reasonings in relation thereto.

Before proceeding to the discussion of the science of electrodynamics, it will be interesting, as well as profitable, to take a brief view of the early history of the discoveries of electricity, and of the popular opinions that have in different ages been entertained in regard to this once deemed "mysterious agency of Nature."

EARLY HISTORY OF ELECTRICAL DISCOVERIES.

The earliest historical records transmitted to us of the discoveries in electrical science, independently of its familiar appearance in the form of lightning, are contained in the writings of the ancient philosophers of Greece, about six hundred years before the date of the Christian era. The fact was first announced by one of them, that "if a piece of amber be rubbed, sparks and flashes of light become perceptible, and straws or feathers are attracted thereby."

It was early noticed, not only that the phenomena of *sparks* were developed by the friction of the amber, but that impulses of mechanical force, in the form of *attraction* and *repulsion* of light freely movable substances, were simultaneously developed.

It is probable that these same phenomena of sparks were familiarly known to the race of hunters, who first peopled the earth, and clad themselves in the soft furs of the animals captured in the chase. The least friction of these furs during dry, frosty states of the atmosphere, whilst worn as garments, and the mere change of them from the warmth of the body to the cold air, must then have excited electric action, as they still continue to do, under similar circumstances.

A recent traveller, Col. Emory, on crossing the range of the Rocky Mountains, in an expedition in the service of the government of the United States, noticed, that "at night, passing my arm over the surface of the fur robe in which I was enveloped, electric sparks were discharged in such quantities, as to make a very luminous appearance, and a noise like the rattle of a snake."

Ancient writers have recorded the appearance of lambent flames on the tips of the spears borne by sentinels on the battlements of lofty towers, during the continuance of thunder-storms; and similar electrical phenomena have frequently appeared on the tips of the masts and yards of vessels at sea, in the form of balls of fire, and lambent flames,—greatly to the terror of superstitious seamen; who have given the names of the "Fires of St. Elmo and St. Anne," and of "Castor and Pollux," to these luminous brushes of electrical light.

These lights appeared to the seamen of former times as mysterious apparitions of restless spirits of the air, flitting from spar to spar, in pale phosphoric gleams, and hovering about the tempest-tost vessel during stormy nights. Many a legendary tale has been repeated by shuddering sailors, during their nocturnal watches on the deck, of ominous warnings of impending shipwrecks and deaths, that have been forewarned by these imagined supernatural agencies.

These electrical lights have not been confined to the level expanse of the ocean. Innumerable cases are recorded where they have appeared on the land. There are published accounts of travellers, who have seen the tips of their horses' ears, and every point of their equipments, and of the twigs of bushes on the road-side, lighted up by lambent flames, during their journeys in dark and stormy nights.

Further details of these phenomena will be given in illustration of "Atmospheric Electricity."

POPULAR OPINIONS RELATIVE TO THE EXISTENCE AND MODES OF ACTION OF AN ALL-PERVADING ELEMENT OF POWER.

In examining the traditionary opinions that have been entertained by mankind, from the earliest ages to the present time, in relation to the supposed existence of the natural forces that govern the movements of the matter composing the universe, it is truly remarkable to find how nearly similar they have been. The suggestions of some of the ancient philosophers, founded on the observations of the palpable phenomena of electricity constantly presented to their view in the visible universe around them, approximate more nearly to modern notions of these phenomena, than most men of the present day are aware of. Although from an ignorance of the discoveries of electrical forces recently brought to light, these opinions may appear to be vaguely conceived, and more vaguely expressed, yet it is interesting, in the course of our progress, to look back upon the less enlightened mental labors of men of other days, as a sort of encouraging excitement to revive our zeal and efforts to make further advancements.

"Lightning consists of fire derived from the sun," was the doctrine of Epicurus, a Grecian philosopher, and as maintained by Lucretius. (De Natura Rerum, book vi.) In bringing down the lightning from the clouds of condensing vapors produced by the intense action of the sun's rays on a sultry day, Franklin simply verified this suggestion of Epicurus.

It was the doctrine of Hippocrates, that there exists "a powerful, although invisible elementary fire, ruling all things without noise, and never in repose; continually actuating and animating the whole system of nature." This account might serve at the present time, even with all the present modern discoveries of science, as a definition of electrical agency.

Pythagoras taught the very transcendental doctrine, that "the great governing principle of nature consists of an all-pervading fiery ether, of boundless energy, possessing within itself the combined power of the *self-moving principle*, and of a *certain intelligence* in self-guidance;" and that "the human soul is a portion of the same essence."

Plato, . Democritus, and other ancient philosophers, have manifested by their writings, their belief that the phenomena of electricity, light, heat, and magnetism, with their ever-accompanying attractive and repulsive powers of action on material bodies, are the governing agencies of nature.

In relation to the knowledge possessed by the ancients, Bishop Berkeley remarks, that "the Pythagoreans and Platonists had a notion of the true system of the world. They knew there was a subtile ether pervading the whole mass of corporeal beings, and which was itself actually moved and directed by a mind."

Pythagoras, after supposing all space to be pervaded by this electrical atmosphere, which he denominated "*ether*," fancied that the planetary orbs must produce hurtling sounds, although inaudible to human ears, such as rapidly hurled missiles produce on passing through the dense medium of our atmosphere; and that the sounds must vary according to the respective velocities and distances of the planets from their common centre. Those spheres which are farthest off, he supposed would produce the deepest tones, and the nearest, the highest tones. From these considerations he was led to advance the poetical idea of THE MUSIC OF THE SPHERES.

To the fervent imagination, the most delightful conceptions of the order and perfection of the mechanism of the universe are presented by supposing the very movements of the parts to produce harmonious measures to "time their marches through boundless space."*

A similar conception of harmonious movements is expressed in the Book of Job,—"The morning stars sang together;" and in the imperishable verse of Addison, the stars are referred to, as

"Forever singing as they shine."

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* This opinion appears to have been humorously controverted by the "Heroine" of a modern novel, who affirmed that "a bullet whistled as it went, for want of thought."

Shakespeare, whose genius trenched as deeply in the philosophy as in the beauties of nature, exclaims,

> "There's not the smallest orb 'mongst all which thou beholdest,
> But in its motion like an angel sings."

Even Kepler, it is stated, commenced his mathematical calculations on the preconceived belief of the existence of this same harmonious musical system resulting from the movements of the planets; and was thus led to compare their consequent distribution at regular proportionate distances from the sun, as the centre of their motions. He realized his anticipations of the regularity of the distances of these orbs from the sun, and succeeded in making the glorious discovery of the great laws of astronomy, which have received the name of "Kepler's Laws," which will perpetuate his name as long as the science of the stars shall endure.

This very remarkable instance of success in effecting discoveries of the secrets of nature, may serve to show that sometimes truths may be elicited by persevering investigations of popular notions of the existence of harmonious order in all the plans of the structure of the mechanism of the universe, and in the systematic working of all its parts, in accordance with established laws, governing the states of motion and rest of matter. Indeed, to suppose otherwise might be deemed to infer a doubt, that "order is heaven's first law."

The phenomenon of the nebulous cone of light which may be seen soon after sunset on any very clear evening about the time of the vernal equinox, and just before sun-rise at the opposite season of the year, denominated the "Zodiacal light," extending from the horizon obliquely upwards, has been supposed to have some connection with this universally diffused electrical atmosphere. Sir John Herschel observes, "It may be conjectured to be no other than the denser part of that medium, which we have some reason to believe resists the motion of the comets." (Outlines of Astronomy, page 616).

Against the probability of the existence of this universally diffused atmosphere of electricity beyond the limits of the atmosphere of our earth, and throughout the depths of space in the heavens, it has been urged, that such a medium would offer a resistance to the movements of the celestial orbs, and would impede and gradually arrest them in their courses.

By recent observations of the movements of the comets, it appears that this resistance has in some degree been actually verified by the fact, which is supposed to have been indisputably proved in regard to the gradual diminution of the velocity of the movements and of the number of revolutions in a given time, of the comet that bears the name of its discoverer, Encke. It has been computed that this comet loses somewhat less than $\frac{1}{1000}$ part of its velocity at each revolution, which is completed in 1208 days; and that in 23,000 years it will lose about one-half of its present velocity.

Admitting these calculations to apply to the movements of the extremely diffused nebulous matter of comets, which are so widely extended in the space of the heavens, this resistance would become hardly appreciable when applied to the momentum of the dense masses of the planets.

About the year 1675, Sir Isaac Newton made numerous experiments upon the action of electrical forces. In the account which he addressed to the Royal Society, he even attempted to compute the probable density and elasticity of an "all-pervading, ethereal substance, capable of contraction and dilation," as a fluid medium compared with air. Founding his calculations on the basis of the propagation of sound as compared with that of light, he supposed that the "imponderable ether" must be at least 700,000 times less dense than air; and that its elastic force, as compared to its density, must be, at the lowest estimate, about 490,000,000 times that of air. In a letter which Newton addressed to the celebrated philosopher, Boyle, in the year 1678, he suggests that this ether is "the cause of cohesion, capillary attraction, and of the force by which menstruums pervade and dissolve solid bodies," concluding this supposition by the further suggestion, that the same ether might also be the cause of animal motion, "although," he says, "we have not that sufficiency of experiments, which are requisite to an accurate determination of the laws by which this subtile fluid operates."

The first treatise on the subject of electrodynamics in more modern times appears to have been written in Latin, and published in England in the year 1600, by William Gilbert, a London physician.

It is worthy of remark, that this sagacious philosopher had anticipated, hypothetically, much of the knowledge which has recently been verified by modern discoveries, of the action of electrical forces. He considered electricity and magnetism to be identical emanations of the same all-pervading, fundamental force. He treated of the earth itself as being practically a huge magnet, affirming his belief that the terrestrial matter is held together by the agency of electrical forces, including even the atoms of every solid mass. He tested the force of the electrodynamic action propagated by means of a frictional electrical machine, by a needle balanced on a pivot, somewhat similar to those subsequently employed by Coulomb, Haüy, and Brewster.

After an interval of about thirty years, Nicholas Caboeus published his electrical experiments; and after the lapse of about a similar interval of time, Boyle published his work on electricity.

Up to the date of about the year 1700, it appears that the process of rubbing sealing-wax and glass with dry, warm cloths, applied by the hand, was resorted to for disturbing the state of rest of electrical matter. Otto-Guericke, the inventor of the air-pump, first used machinery for causing a globe of sulphur to revolve, whilst he held with his hand various kinds of substances as *rubbers*, to produce friction thereon.

In the last century philosophers entertained a belief "in the existence, in all bodies, of an exceedingly elastic and active principle," which they denominated "PHLOGISTON." The disengagement of this principle during the process of combustion was supposed to produce the phenomenon of "fire." A doctrine was subsequently advanced by the celebrated philosopher Des Cartes, that the movements of the heavenly bodies are caused by vast whirlpools of a subtile matter, which extends to the utmost limits of the universe, the sun being placed in the centre of this vortex of subtile matter of our system of the great whirlpool. This theory appears to have absorbed the attention of the learned for a considerable period of time, with divided opinions of the probabilities of its truth.

Bacon next advanced a theory of natural motive power, affirming that all kinds of matter are reducible to two classes, viz., "ACTIVE and PASSIVE MATTER."

The active matter he alluded to as a "rare, invisible, and, although imponderable, yet a real quantitative substance, pervading and filling the spaces of all gross bodies." The active matter referred to by him, is evidently the electric matter, all other kinds being included by him in the other class of "passive" matter.

Franklin and Priestley referred all electrical phenomena to the action of a peculiar matter, which they considered as identical with "*phlogiston.*"

Nollet advanced still further, affirming his belief that electricity is the elementary fire, which produces heat, light, and magnetical and chemical actions. Wilke, Hube, and Ritter, after having made a great number of experiments upon the chemical properties of the Pile, entertained similar ideas.

Indeed, so palpably and universally observable are the phenomena developed by the electrical action, that there is probably no intelligent individual who has not entertained some kind of theoretical view of its agency in connection with the mechanism of the universe. A pioneer in one of the wilds of a western forest, once addressed to me his speculative notions, after noticing the sparkling flashes, which occasionally become manifest between the clefts of wood when suddenly laid open by the axe, affirming his belief, that the cause of fire exists in the wood, and becomes manifest in burning.

Thus it appears that human intelligence, in every age and in every part of the earth, has been continually busy in making observations on the phenomena of the material world, amid which it exists. Experience teaches us to respect opinions that have been sustained by the result of long-continued observations, and to hesitate in rejecting them, until after passing through the ordeal of the tests of modern science.

The details of the numerous speculative theories that have just been recapitulated relating to the causes of the natural movements of bodies, advanced by men of former days, may serve to abate the zeal of starting original theories, and the pride of opinion in maintaining them, whilst they serve to stimulate investigations instituted to verify them.

ON THE MATERIALITY OF ELECTRICITY.

The occupancy of Space by a perfectly Mobile Fluid, capable of propagating Impulses of Mechanical Force, considered as a Test of the Materiality of Electricity.

No manifestation of any discoverable weight of electric matter having been detected by means of accumulating electric excitation in bodies placed in the most delicate balances, chemists have classed electricity with heat and light, as "*imponderable agents.*"

But considering electric matter to be universally diffused as an all-pervading atmosphere, or medium, and perfectly mobile, it might theoretically be anticipated to be as difficult a task to weigh this fluid in the medium by which it is surrounded, as to weigh the grosser air without the ability of excluding the atmosphere from the flask.

From the facts of the imponderability and exceeding subtileness of electricity, the most discordant opinions have been advanced by eminent philosophers, whether it be absolutely matter, or only a property of material bodies.

In a treatise on Chemistry, by Professor Graham, in very general use as a text-book in schools, he denies that there is any evidence of the existence of electricity independent of matter; and, consequently, he leaves it to be inferred that electricity, like the vital principle, must exist as an immaterial essence in connection with matter, or else that electrical phenomena are inherent properties of matter.*

On this question of the materiality of the imponderable agents, Rumford made a series of experiments by means of exciting heat by friction, in the process of boring heavy cannon. He found that, notwithstanding the most careful insulation of the cannon and boring apparatus, by surrounding them with non-conductors of heat, still sufficient heat was generated by the intense friction, to keep water boiling during several hours, or as long as the process was continued. Hence he argued that, as the heat in this case could not have been drawn from adjacent bodies, or the air, and as there was no appearance of it in the metal of the cannon, or in that of the boring apparatus, previously to the commencement of the operation, this heat must have been created by the friction of the parts in contact; and as friction is a mere mechanical process, and nothing material in itself, that consequently, all this extraordinary quantity of heat must have been actually created out of nothing. And as material bodies can neither be created out of nothing, nor annihilated when once created, he concluded that heat must be *immaterial*, or nothing.*

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* Graham's Chemistry, Am. edition, page 158.

Dr. Hare considers that, agreeably to the recent speculations of Professor Faraday, both the causes of heat and of electricity exist in metals; and that these causes must consist of material, independent, imponderable matter, occupying the whole of the space in which their efficiency is perceptible. "To the evolutions of the imponderable matter thus associated, the incandescence of a globule of potassium, in contact with water, may be ascribed, since it is the consequence of the displacement of such matter by the elements of water, which, in displacing it, converts the metal potassium into the hydrated oxide called caustic potash."†

In the very popular treatise on Chemistry of Dr. Turner (republished by Gregory and Liebig), it is stated that "the effects of electricity are so similar to those of a mechanical agent,—it appears so distinctly to emanate from substances which contain it in excess, and rends asunder all obstacles in its course so exactly like a body in rapid motion, that the impression of its existence, as a distinct material substance, *sui generis*, forces itself irresistibly on the mind. All nations, accordingly, have spontaneously concurred in regarding electricity as a material principle: and scientific men give a preference to the same view, because it offers an easy explanation of phenomena, and suggests a natural language intelligible to all."

Professor Whewell "doubts whether the hypothetical fluids, electricity, heat, and light, termed *imponderable*, depend at all upon transferable fluids."

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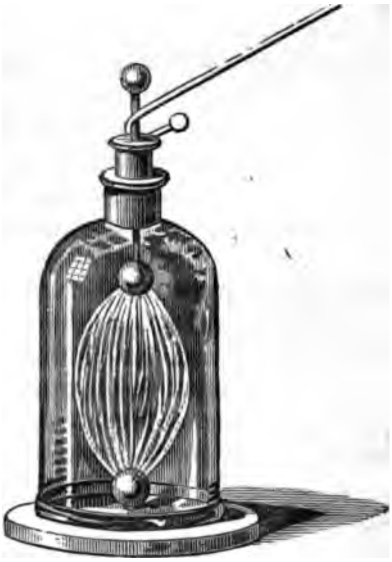
* In the same style of reasoning, a directly opposite conclusion may be arrived at, by humorously supposing that what is material cannot be acted upon by nothing, or by what is immaterial; and as the heat of a cup of tea often acts upon our lips, which are material, as all will admit, therefore heat must be material. By indulging in these hypothetical reasonings it may thus be asserted of heat, and of electricity, as of the "trash" in the stolen purse—"'Tis something,—nothing."

† Dr. Hare's Treatise on the Theories of Electrical Phenomena.

Professor Faraday's opinion, that electricity is not to be found existing by itself, appears to be rebutted by Sir Humphrey Davy's statement, that electricity pervaded the most perfect vacuum he could make by means of an air-pump, as tested by the lambent flashes, which are familiarly exhibited in the lecture-room, as shown in the figure.



The fact that electricity is not found to become manifestly discoverable independently of gross matter, might have been anticipated from what has been premised; for it is only by the mechanical action of electricity on the material parts of electroscopes, electrometers, galvanoscopes animal nerves, muscles, &c., that human powers of perception are enabled to take cognizance of its presence.

In referring to the beautiful coruscations of electric flashes pouring like a cascade of fire from the upper to the lower ball in the vacuous space of a bell-glass, Mr. Sturgeon exclaims, "What a fund of intelligence is opened to our view by the display of this beautiful phenomenon! An electric atmosphere is here exhibited, and is found no longer to exist in the imagination alone."

The cavity of the exhausted vessel becomes lighted up by brilliant coruscations, that will dart in lambent flames throughout the whole extent of a tube six or eight feet in length; and for a considerable time after the connection with the excited conductor of the electric machine is cut off, flashes become perceptible at intervals, resembling those of the phenomena of "heat lightning," which illumines the fringes of the summer-evening clouds.

If the discharge of the electricity from a glass bottle coated with metal be caused to take place through a long glass tube *partially exhausted of air*, to represent the actual condition of the earth's atmosphere just above the clouds, instead of the phenomenon of lambent flames pervading the interior of the tube, as occurs in the preceding experiment, the discharge takes place in a more condensed form, like fire-balls falling through the tube; thus closely resembling in appearance the phenomenon of the meteors frequently observable in the evening sky, and popularly called "shooting stars."

At the height of sixty or seventy miles above the earth's surface, the rarity of the atmosphere becomes about equal to that which exists in a glass vessel after being exhausted by means of an air-pump; and, consequently, we might anticipate that this vacuous space of the heavens may serve for the free passage of the electricity throughout its whole extent, as does actually occur in the phenomenon of the AURORA BOREALIS.

The above-stated experiment of the transmission of a current of electricity through the vacuous space of a glass tube exhausted of air, presents to view a very exact resemblance to that exhibited in the flickering coruscations of light in the heavens, denominated the "aurora borealis," or "northern morning." The intermediate regions between the arctic and antarctic poles and the temperate zones, become oftener lighted up by these coruscations than the equatorial, or extreme polar regions of the earth, the currents being probably more intense in their transit between these differently excited parts of the earth's surface.

The daily revolution of the earth on its axis, subjects different portions of its surface successively to the electro-dynamic action of the sun. This continuous movement must produce a continuous disturbance of the state of rest of the electric matter existing in connection with its surface, and the consequent movement of it continuously in the form of electric currents from east to west, about its equatorial parts. This fact will presently be demonstrated. But as the two opposite poles of the earth are only exposed gradually toward the sun alternately once during a whole year, the terrestrial electric currents diffused from the equatorial regions of the earth toward either pole must consequently be comparatively feeble, and determinable rather by contingent circumstances of local disturbances of the electrostatic condition of the polar and equatorial parts of the earth's surface. Professor Faraday has suggested the existence of electric currents induced from the excited equatorial regions of the earth toward the frigid polar regions, and the probability of returning currents passing from the poles of the earth into the atmosphere in the streaming flashes of the aurora borealis.

That the light of the aurora borealis is truly an electrical phenomenon, appears to be verified by the action in the magnetic needle, which Capt. Ross stated to have been turned aside nearly forty degrees, when the coruscations were flashing nearer to the surface of the earth than usual during his exploring expedition. In treating of electro-magnetism, it will be presently shown that this same effect is produced by the movement of electric currents near magnetic needles.

From the calculations of Mr. Cavendish, the light of the aurora borealis usually appears at an elevation of about seventy English miles above the earth's surface; at which elevation the atmosphere must be of only about $\frac{1}{148567}$ part of its density at the earth's surface; a degree of rarefaction far above that afforded by our best air-pumps.

It appears by the result of observations of the angles of the elevation of an aurora borealis, which were simultaneously noted at different places in England, that some of the coruscations occurred at an elevation of about 175 miles above the earth's surface.

These facts confirm the belief that the depths of space, instead of being void, are occupied by the subtile fluid of one vast electric ocean, shoreless and bottomless, the least disturbance of the statical conditions of which serves to propagate electro-mechanical impulses adequate to acting upon the material nerves of sentient beings, and through them upon the mass of the brain, to produce the sensations recognizable by the tribunal of human intelligence located there, as perceptions of light and of heat.

These phenomena present apparent proofs of the existence of electricity as independently of terrestrial matter as the nature of things will admit; and if the fact of the occupancy of space by electricity be once established, then it follows that we have this test as the strongest possible proof of its being material, showing the certainty, as observed by Sir Humphrey Davy, "that there is matter moving in the space between us and the heavenly bodies, capable of communicating heat, whatever theory of it may be adopted."

ATMOSPHERIC ELECTRICITY.

The facts as yet developed by experiments upon atmospheric electricity are too scanty and vaguely ascertained, to serve as the basis of mathematically exact calculations of the relative states of electrical intensities at different elevations from the earth's surface. Every superior stratum has been generally found to be more highly electric or *positive*, than the one beneath it.

Finding thus by observation that space is so freely occupied by electrical matter, and knowing that as we recede from the surface of the earth, each succeeding portion of the atmosphere more remote therefrom, contains less matter of the air, and consequently exhibits more nearly the condition popularly denoted by the term "void space," we have reason to believe that there *is no void space in the universe.* The very spaces between the atoms of the most dense solid bodies, as well as between the most attenuated particles of air left in an exhausted receiver after human art has accomplished the most perfect possible void, alike exhibit indications of the presence of electric matter, as tested by every cause of the disturbance of its electrostatic condition.

This electrical matter serves as a material medium to propagate impulses of mechanical force in the form of the action recognized as that of the "heat" and "light" of the sun, and of "gravitation," as will be presently illustrated. With this view of the mechanical agency of electrical matter, we are relieved from the embarrassing idea of the possibility of the propagation of dynamic action between the distant orbs of matter in the heavens, without any intervening material connection between them.

And by adopting this view of the general diffusion of a fluid medium throughout all otherwise unoccupied space, we may rationally conclude that such a fluid must necessarily act upon the bodies immersed therein, by regular laws, like those of atmospheric or hydrostatic pressure. So many of the powers of action of the electric fluid agree with the laws of motion and force established by our knowledge of mechanical science, as to induce us to suppose that the phenomena of the motion and force of electricity are governed by similar principles to those which control the movements of all other passive matter. As observed by Mr. Sturgeon, "the experiments that may be brought forward in favor of the electro-mechanical forces being subjected to the same laws as govern pneumatic pressure, are not only numerous, but satisfactory, as far as present means of experimental admeasurements admit of approaches to accuracy."

The facts of the excitation of ocean water into steamy vapors by the electrodynamic action of the sun, and of their subsequent ascent into the lofty regions of the air, where the vapors become condensed, and the electrodynamic action diffused in the form of *lightning*, are sufficient to lead us theoretically to anticipate frequent and violent reactions of this kind on mountain-tops, and among the clouds in the upper regions of the air.

On ascending to the tops of lofty mountains, the frequency of electrical disturbances has been a common subject of remark by travellers. The following description of electrical phenomena on mountain-tops is given by a recent traveller, Professor Forbes, who ascended one of the peaks of the Alps to an elevation of 9000 feet above the level of the sea.

The ground, he states, was covered with half-melted snow; and the end of the iron-shod staff, which travellers on the frozen surface of the Alps always use to aid them in their explorations of the slippery ascents, first gave evidence of the discharge of electricity from the air. On holding his hand above his head, "his fingers gave a whizzing sound, and all the angular stones around were perceived to be hissing, like points near a powerful electrical machine."

Captain Wilkes states, in the account of the ascent of Mauna Loa, in one of the isles of the Pacific Ocean, that "during the whole time that we were above the height of 9000 feet, there were only one or two days in which the electrical excitement of the atmosphere was not apparent; and these were exceedingly damp. The electroscope, in fact, was in constant action during our stay."

Near the level of the ocean, there appeared at Algiers, in 1831, to a number of French officers,* "a white light, in the form of a tuft, surmounting the flag-staff, continuing for half an hour. The officers, who were on horseback on the terrace, were very much astonished at beholding similar small tufts of light beaming from the ears of their horses. On elevating their hands, similar brilliant tufts appeared to surmount the ends of their fingers. Every one exposed to the action of the atmospheric electricity experienced muscular contractions, and a general lassitude, but principally in the legs."

Mr. Crosse arranged insulated conducting wires on the tops of tall poles above the highest branches of the lofty trees that surrounded his residence, and extended them to a distance, horizontally, like the telegraphic wires now commonly arranged between distant cities. The end of this wire was terminated in a brass conductor, insulated, and fixed on a table in his electrical room.

"About four o'clock in the afternoon I suddenly heard a very strong explosion between the two balls, and shortly after many more took place, until they became one uninterrupted stream of explosions, which successively died away and recommenced with the opposite electricity in equal violence. The stream of fire was too vivid to look at for any length of time, and the effect was most splendid, and continued without intermission, save that occasioned by the interchange of electricities, *for upward of five hours*, and then ceased totally. During the whole day, and a great part of the succeeding night, there was no material change in the barometer, thermometer, hygrometer, or the wind, which was not high, but blew steadily from the southwest. The least contact with the conductor would have *occasioned instant death.*"

"In every acre of fog there was enough of accumulated electricity to have destroyed every animal within that acre."

By incautiously exposing himself to the action of atmospheric electricity, transmitted by conducting wires into his study, Professor Richman was instantaneously struck dead by one of the discharges.

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* Voyage dans la régence d'Alger, par M. Roset.

The wires of electric telegraphs, being similarly exposed to the excitation of atmospheric electricity, serve to exhibit occasionally violent discharges of electricity, which are sometimes adequate to operating the lever of the electro-magnetic instruments employed; simultaneously exhibiting such powerful developments of electro-dynamic action, that the instruments cannot be managed. Where arrangements of conductors connected with the earth have not been made for the escape of this extraordinary surplus, the safety of the operators has in some cases been endangered, and disruptive discharges, producing sounds as loud as those of firearms, have occurred in the telegraphic offices. Even during calm, clear weather, the workmen have sometimes found it a difficult task to fix the wires upon the posts, overpowering, benumbing sensations being produced in their hands by contact with the wires.

Immediately after the invention of coating glass jars with metal, denominated Leyden jars, from the name of the city where the invention originated, it became a common subject of discussion among philosophers to establish proofs of the identity of the violent disruptive discharges, of the Leyden jar, and of thunder clouds.

Impressed with this belief, Franklin made arrangements to test the truth of the supposition by fixing a conducting wire high in the air on the top of a spire, which workmen were employed in erecting in the city of Philadelphia, hoping by this means to collect electricity from passing clouds. Whilst impatiently awaiting the slow progress of the workmen, he noticed a boy's kite, elevated to a great height above the unfinished spire; and immediately conceived the plan of resorting to this expedient for elevating the end of a kite string, instead of a conducting wire, to make the desired experiment.

Having constructed a kite by stretching a large silk handkerchief over two sticks, bound together in the form of a cross, on the first appearance of an approaching storm, in June 1752, he went out into a field, accompanied by his son, to whom alone he had imparted his design. He raised his kite, and attached a key to the lower end of the hempen string, the end of which he *insulated* by means of a silk cord fastened to a post; and then he waited with intense anxiety for the result. A considerable time elapsed without the apparatus giving any signs of electricity, although a dense cloud, apparently charged with lightning, had passed over the kite.

Franklin was just beginning to despair of success, when his attention was caught by the bristling up of some loose fibres on the hempen cord; then he presented his knuckle to the key, and received an electric spark.

In the interesting account given of this bold experiment, it is stated, "overcome with the emotion inspired by this decisive evidence of the great discovery he had achieved, he heaved a deep sigh, and conscious of an immortal name, felt he could have been content, if that moment had been his last."

"The rain now beginning to fall in torrents, and wetting the string, rendered it a better conductor throughout its whole length, so that the truth of his conjecture was verified by the appearance of the electricity in a continual stream of sparks."

Thus he happily accomplished the task of drawing down the lightning from heaven, as beautifully expressed by a French writer, in a subsequent allusion to his exertions in the cause of Freedom:—

"Eripuit cœlo fulmen, sceptrumque tyrannis."

He seized the thunderbolt from heaven, and the sceptre from tyrants.

It has been determined by the course of observations made by De Saussure, Arago, and others, that the electricity of the atmosphere is subject to diurnal variations of intensity, there being two maxima and two minima during the twenty-four hours. The first minimum takes place a little before the rising of the sun; as it rises the intensity becomes first gradually, and then rapidly increased, until it arrives at its maximum, a few hours after. And in like manner, this excess diminishes, at first rapidly, and afterwards slowly; and arrives at its minimum some hours before sunset. The intensity again becomes increased when the sun verges toward the horizon, and attains its second maximum a few hours after, then diminishing again until sunrise, thus continually recurring in daily ebbing and flowing tides of electrical excitation.

The greatest disturbances of the natural electro-static conditions of terrestrial matter is found usually to take place in the winter, when there occurs the most sudden changes of temperature; whilst the moisture of bodies is then reduced to crystals of ice, and they do not so freely as in summer allow of the propagation of electric actions and reactions to restore the equilibrium of the disturbed electric conditions. These facts disclose the daily disturbances of the natural electro-static conditions of bodies by the electro-dynamic action of the sun.

That there are developed overpowering impulses of mechanical force, simultaneously with extraordinary development of electric excitation of the atmosphere, is so often a subject of remark, that the term of "thunder-gust" has become a familiar expression to denote the violent action of the wind, which frequently accompanies the passage of clouds highly charged with electricity. The phenomenon of vivid flashes of lightning almost invariably accompanies the terrific course of tornadoes, as has been noted by Dr. Hare.

By recurring to a letter from the writer, addressed to Dr. Hare, and published by him in the Transactions of the American Philosophical Society in 1838, containing an account of a tornado which passed over the city of Providence, it is stated, "the tornado soon swept towards an extensive range of buildings within a few yards of me, the roof of which appeared to open at the top, and to be uplifted for a moment. The whole fabric then sunk into a confused mass of moving rubbish, and became indistinctly visible amid the cloud that overspread it, as with a mantle of mist.

"The destructive force of the tornado now became not only apparent to the eye, but also fearfully terrific, from the deafening crash of breaking boards and timbers, startling the amazed spectator in alarm for personal safety, amid the roar of the whirlwind, and the shattered fragments, flying like deadly missiles in the air. At one instant, when the point of the dark cone of the whirling cloud passed over the prostrate wreck of a building, the fragments seemed to be upheaved as if by the explosion of gunpowder, and I actually became intensely excited with the fear that the moving mass might direct its march toward the open area of the yard, to which I had resorted, after abandoning the building in which I had previously found a shelter.

"In crossing the river, the circle formed by the tornado on the foaming water was about three hundred feet in diameter. Within this circle the water appeared to be in commotion, like a huge boiling caldron; and misty vapors, resembling steam, rapidly arose from the surface, and entering the whirling vortex, at times veiled the centre of the circle, and the lower extremity of the overhanging inverted cone of dark vapor. The waves heaved and swelled, wherever the point of this cone passed over them, apparently as if some magical spell were acting on them with the effect of enchantment. *Twice I noticed a gleam of lightning, or of electric fluid, to dart through the column of vapor, which served as a conductor for it to pass between the water and the cloud. After each flash, the foam of the water seemed immediately to diminish for a moment, as if the discharge of the electric fluid had served to calm the excitement on its agitated surface.*"

"The above imperfect sketch can convey to your mind only a faint impression of this exciting scene, causing just terror enough to impart to the spectator the most awful sense of the sublime power of the Almighty, as described in the glowing words of the Psalmist:—'He bowed the heavens also, and came down; and darkness was under his feet; and he did fly upon the wings of the wind. He made darkness his secret place: his pavilion round about him were dark waters and thick clouds of the skies.' "

In Captain Scoresby's account of the remarkable ethereal phenomena accompanying a hail-storm, experienced by the packet ship New-York, he states that "the sea was in continual boiling agitation, as if acted upon by numerous submarine volcanoes. Three columns of water were perceived to be upheaved into the air, and to fall back again in foam into the sea, which was violently agitated by the shock. All the knives and forks on shipboard were rendered strongly magnetic; one of them being rendered capable of lifting a piece of iron weighing 228 grains," &c. The magnetizing of steel being a familiar effect producible by electric action, the phenomenon of the remarkable development of forces displayed in upheaving the masses of water during this hail-storm, appears to be ascribable to the excitation of electro-dynamic impulses.

Our restricted limits will not allow of pursuing further these interesting details of the propagation of impulses of mechanical force originating from the sun through the passive medium of electric matter, in producing static and dynamic conditions of FLUID SPHERICAL FORMATIONS. Our attention will now be devoted to the consideration of—

SOLID INORGANIC FORMATIONS.

THE GROUPINGS OF ATOMS INTO SOLID INORGANIC FORMATIONS, AND THE CHARACTERISTIC PROPERTIES OF MATTER, TRACEABLE TO THE CONTINUOUS PROPAGATION OF THE ELECTRO-DYNAMIC ACTION OF THE SUN.

The mere occupancy of space by atoms of matter, without reference to the groupings of them into "Formations," constitutes our idea of the original chaos, when "the earth was without form and void." The groupings of atoms into various solid inorganic and organic formations, represents the original "creation."

By analyzing the various groupings of atoms composing the crust of our planet, chemists affirm that they have detected the existence of about "sixty different kinds of simple elementary substances." And yet no chemist has ever recognized the existence of an individual atom of matter. It is only of groupings of atoms into molecules, or masses of sufficient magnitude to become appreciable by human powers of perception, that chemists have taken cognizance in their qualitative analyses. One of the most eminent chemists of the age, Professor Faraday, affirms, that "all our knowledge of the atom, and even our fancy, is limited to its powers." The science of chemistry, as well as that of mechanics, can therefore take cognizance only of the "powers" of atoms as grouped into a discoverable mass,—not of the individual atoms of the mass.

The groupings of atoms into masses of solid inorganic and organic formations being mechanical effects produced by continuous mechanical impulses, it follows, that the continuous propagations of these mechanical impulses constitute the "powers" to which Professor Faraday refers, as constituting all our knowledge of the atom. When, therefore, chemists assert the existence of "sixty kinds of simple elementary substances," it is manifest that they can only refer to the existence of this specific number of kinds of groupings of atoms, which they recognize by their several characteristic powers of continuously propagating sixty distinctly modified grades of mechanical impulses.

In recapitulating the number of kinds of vegetable organic formations, botanists affirm, as the result of their discoveries, that there exist many thousands of different kinds of plants, each having a different form, and exhibiting differently modified powers of developing action—as fuel, food, poisons, medicines, acids, alkalies, &c. But botanists do not presume to affirm that there exist several hundred thousands of "different kinds of matter," because they find this number of groupings of atoms endued with distinct external forms and internal characteristic powers. In like manner zoölogists, in affirming that they have discovered the existence of about 250,000 different kinds of animal organic formations, each having a different form, and exhibiting a systematically graded scale of characteristic powers, do not assert the existence of an equal number of kinds of matter.

But the chemist, on the contrary, when he finds about sixty groupings of atoms of lifeless inorganic formations, many of them of the same crystalline forms, but exhibiting sixty differently modified grades of powers of propagating action, as acids, alkalies, &c., positively affirms that there exist an equal number of kinds of simple elementary atoms; whilst at the same time he confesses that "all his knowledge of the atom, and even his fancy, is limited to its powers," and the microscopist affirms that he can never even hope to discover the existence of an individual atom of matter.

These considerations lead us to believe, that the First Cause has seen fit to endue about sixty specific kinds of groupings of atoms of inorganic formations with sixty specific grades of powers of modifying, reciprocally, in directions between their respective centres, the propagation of the electro-dynamic action of the sun; in accordance with the similar system of the endowment of about a dozen kinds of the groupings of the same atoms into organic formations of the mechanisms of vegetable and animal bodies with hundreds of thousands of different specific kinds or grades of powers of modifying continuously the propagation of the same electro-dynamic action of the sun. This plan establishes a perfect harmony between the systems of inorganic and organic formations.

The broad scope of the system of investigations, which we have commenced upon, will not permit of the appropriation of further time here to pursuing the trains of facts of the groupings and separations of atoms, which it is the peculiar province of another branch of mechanical philosophy, constituting the science of chemistry, elaborately to trace out in detail. It is our present design only to generalize and classify facts demonstrative of a perfect system of the continuous propagation of impulses of mechanical force through the medium of electric matter, from a source ninety-five millions of miles distant from the earth; and of the continuous propagation of such impulses between portions of terrestrial matter, at insensible and sensible distances, producing both the solid static inorganic and organic formations, and the dynamic impulses resulting from every such change of static conditions.

ON THE NUMBER OF KINDS OF INORGANIC GROUPINGS OF ELEMENTARY SUBSTANCES.

The preceding observations teach us to infer that the subdivision of terrestrial matter into "elementary substances," has reference to a systematic classification of powers of modifying the propagation of the electro-dynamic action of the sun, rather than to any essential difference between the individual atoms of passive matter.

In treating of molecular action, Buscovich considers atoms as centres of forces. Professor Faraday "considers the atom as something material, having a certain volume, upon which those powers were impressed at the creation, which have given it from that time to the present the capability of constituting, when many atoms are congregated together into groups, the different substances, whose effects and properties we observe." And in explaining his views of the characteristic properties of an elementary atom, Professor Faraday even expresses the transcendental idea, that there is no necessity for the consideration of the existence of matter at all, any further than as a representation of the existence of a sort of centre of natural motive power: as appears by the following speculation, contained in his communication to the London, Edinburgh, and Dublin Philosophical Journal, dated January 25th, 1844.

"A mind, just entering on the subject, may consider it difficult to think of the powers of matter, independent of a separate something to be called the *matter;* but it is certainly far more difficult, and, indeed, impossible, to think of, or imagine, that *matter*, independent of the powers. Now the powers we know and recognize in every phenomenon of the creation, the abstract matter in none; why then assume the existence of that of which we are ignorant,—which we cannot conceive, and for which there is no philosophical necessity?"

The views of this eminent philosopher, suggesting that "powers of matter" may be developed independently of the existence of matter itself, although somewhat metaphysical, serve nevertheless to set forth in a strong light the importance of mechanical action as being the basis of human perceptions and knowledge of the natural world.

In pursuing his scientific researches, Dr. Hare appears to have arrived at nearly the same conclusion as Professor Faraday. "I presume that there must be at least three different kinds of matter, to each one of which one of the properties specified innately appertains," &c. (Hare's Chemistry, 4th Edition, page 3.)

These reasonings of modern scholars certainly approximate to the doctrine of the ancient school of Greek philosophers, who maintained the existence of only one element of matter.

Excluding every metaphysical speculation, it may be argued from the analogy of the endowment, by Creative Power, of about half a dozen kinds of elementary atoms grouped into organic formations, with a quarter of a million of different grades of powers of modifying the propagation of the electro-dynamic action of the sun, that it is possible, nay, probable, that the same Creative Power may have extended a similar system of the endowment of homogeneous elementary atoms, grouped into inorganic formations, with sixty different grades of powers of modifying the propagation of the same electro-dynamic action.

In calling groupings of atoms of elementary substances, *simple*, it is by no means to be understood that they are unquestionably so. More than a dozen substances, supposed to be simple at the commencement of the present century, have been discovered to be composed of groupings of two or more different kinds of matter. Four new elementary substances have been discovered in the ores of platinum alone, since the year 1803. Doubts have even been expressed, whether many substances now deemed to be simple, may not be composed of two or more different kinds of groupings of atoms. Dr. Turner affirms, "we have no absolute certainty that even chlorine and potassium are simple." Organic chemistry, "the science of compound radicals," exhibits so many instances in which compound groupings of atoms behave precisely like simple elementary substances throughout all the changes of chemical decomposition, and recompositions, that the most scientific chemists become the most prone to suspect the apparently simple character of the sixty popularly acknowledged elementary substances.

So intimately connected are the groupings of atoms of inorganic formations on the surface of the earth, that the mere separation of a new portion from the others, has been deemed a discovery of such rare merit in the observer, as to reward his researches with a fame which will endure until the records of science become lost "amid the wreck of matter."

The propagation of the electro-dynamic action of the sun, through intervals of space, varies in the ratio of the squares of the intervening distances. Consequently there must be some compensating law of electro-dynamic action and reaction, which equalizes this propagation to the planets nearest to, and farthest from, the sun,—to Mercury and to Neptune; or else there must be established different laws of the propagation of this action between portions of matter at sensible and insensible distances, constituting the masses of each of the planets. Otherwise, the groupings of atoms which exist as fluid water on the surface of our planet, must exist as steamy vapor on the surface of Mercury, and as solid crystals of ice on the distant planet Neptune.

In either case, the blood which circulates in the throbbing arteries of animals on the earth, would be reduced to a very different mechanical condition in the arteries of animals resident on the two above-named planets.

With these speculations, however, we have no present concern, as there remains too ample a field for physical researches on the surface of our own planet.

In pursuing our investigations into the conditions of the groupings of lifeless inorganic formations of terrestrial matter, we shall continue to follow up the preceding principles of the systematic establishment of a scale of modified powers of propagating electro-dynamic action and reaction. The elementary substances will therefore be considered in the order of their electrical relationship to each other.

The celebrated chemist Berzelius appears to have taken the lead in advancing the theory of the electrical order of relationships of the several kinds of elementary substances; although it appears from the tenor of the terms used to define the Franklinian theory of electricity, that a similar idea must have prevailed previously, as the words of the following quotation therefrom evidently show.

"All bodies in their natural state are charged with a certain quantity of electricity, in each body this quantity being of definite amount."

The order of the electrical relationship of bodies is practically demonstrable by plunging the ends of two wires, severally connected with the two poles of a galvanic battery, in solutions of various compound substances. The atoms of one kind of substance in every compound become grouped about one particular pole, and the atoms of the other substances about the opposite pole.

It was in this way Davy discovered that potash and lime are compound substances, the atoms of a new glittering silvery metal appearing collected about one of the battery poles, and the atoms of oxygen, previously combined inseparably therewith, appearing clustered in air-bubbles at the opposite pole. He was thus enabled to astonish the world by the announcement of the fact, that the limestone rocks and potash, once considered to be simple substances, are constituted of metals of a silvery lustre, united with carbonic acid gas.

A single atom of any one of the elementary substances does not manifest a decided tendency to become moved toward either pole of the battery circuit, being apparently indifferent to both. Without reference to the electrical condition of other atoms, and taken by itself, an atom of matter becomes absolutely devoid of all power of exciting action, for it can have nothing to receive action. As observed by Professor Bache in a note to his edition of Turner's Chemistry (page 108), "substances considered singly, are neither positive nor negative; nevertheless they are capable of exciting each other by being first brought into contact, and then separated. If two substances touch each other, and be then separated, one will become positive and the other negative. These positions are rigidly exact with respect to all the simple substances except oxygen and potassium, which are absolute; the former being negative to all other substances, and the latter positive to all others."

A regular order of preference is found to take place between nearly all the several different kinds of elementary atoms except hydrogen, carbon, and some few others, which have been determined by their regular order of chemical relationship.

As those groupings of atoms in solutions behave toward each other precisely as they behave toward the excited end of the wire constituting the pole of a galvanic battery, this analogy of reciprocal electro-dynamic action may be deemed complete.

One of the most striking circumstances illustrative of the supposition that each kind of elementary substance has its own peculiar intensity of electric condition, is the analogy of the "specific heat" of each of the several kinds of elementary substances. "Every substance has a specific heat peculiar to itself," as stated by Dr. Turner.

That the groupings of several kinds of elementary atoms into discoverable magnitudes are associated with specific intensities of electro-static actions and reactions, constituting the phenomenon recognized as "specific heat," in a regular increasing ratio or scale, appears to be established by the discovery of Dulong and Petit, showing that there exists a relationship between the weights of each ultimate atom and its specific heat. They determined the following important law:—"The product of the specific heat of each element, by the weight of its atom, is a constant quantity."

It appears by the researches of Dulong and Petit, that "simple atoms have the same capacity for heat;" and that, consequently, "the specific heat of a body would thus afford the means of fixing its atomic weight."

Anticipating (what we shall hereafter prove) that the phenomena of the actions of heat and electricity are alike reducible to electro-mechanical action, and identical with it, the preceding law conclusively demonstrates the fact, that each kind of elementary substance must be endued with the power or faculty of propagating a regularly modified gradation of electro-dynamic action and reaction.

It might be supposed that if all elementary atoms were homogeneous, that there might be artificially producible transmutations of groupings, and consequently of characteristic properties, as was once a favorite idea of the alchemists, which induced them to essay the transmutation of copper into gold. In answer to this objection it may be stated, that if the Creator has seen fit to endue sixty specific portions of groupings of atoms of inorganic formations, with sixty different specific grades of powers of modifying the propagation of the electro-dynamic action of the sun, there could be no more possibility, by any art of alchemy, of transmuting these powers from one portion to another, than of transmuting the characteristic powers of the organic formations of a horse into that of a cow.

Table of Groupings of Atoms into Simple Elementary Substances, arranged in the order of their Electrical Relationships.

NAMES OF SUBSTANCES.	BY WHOM DISCOVERED.	CHARACTERISTIC PROPERTIES.	Relative Weights of the Atoms.
Oxygen	Priestley, 1774	An elastic gas	8·00
Sulphur	In the earliest ages	A brittle substance, softens at 32°	16·00
Selenium	Berzelius, 1818	" " " at 212°	39·57
Tellurium	Muller, 1782	A metal, fuses below red heat	66·14
Nitrogen	Rutherford, 1772	An elastic gas	14·00
Chlorine	Scheele, 1774	" "	35·50
Chromium	Vauquelin, 1797	A brittle metal, very infusible	28·15
Molybdenum	Hielm, 1782	" " infusible at red heat	47·88
Boron	Davy, 1807	An olive-colored substance, infusible at red heat	10·90
Vanadium	Selfstrom, 1830	A metal of silvery lustre	68·55
Tungsten	D'Elhyart, 1781	" of copper color	94·64
Antimony	Basil Valentine, 1490	" of white lustre, fuses at 810°	129·03
Columbium	Hatchett, 1801	" of iron-gray color, nearly infusible	92·30
Titanium	Gregor, 1791	" in blue powder, "	24·29
Silicium	Davy	An olive-brown substance "	21·35
Osmium	Tennant, 1803	A metal in lustrous powder	99·56
Bromine	Balard, 1826	A substance usually liquid, and of reddish color	78·26
Iodine	Courtois, 1812	An opaque fusible solid substance	126·36
Fluorine	Gay-Lussac, 1810	Colorless fluid at the temperature of 52°	18·70
Phosphorus	Brandt, 1669	A soft waxy substance	32·02
Arsenic	Found in native state	A metal of steel gray lustre and brittle	175·00
Carbon	" "	Constitutes the diamond, coal, and charcoal	6·00
Cerium	Hisinger and Berzelius, 1803	A granular metallic substance	46·00
Lanthanum	Mosander, 1840	" " "	48·00
Dydymium	" "	" " "	
Yttrium	Cadslin, 1794	A metal of grayish black lustre	32·20
Cobalt	Brandt, 1733	" of reddish gray color, brittle and fusible	29.52
Nickel	Cronstadt, 1751	" resembling silver	29·57
Iron	Earliest ages	Familiarly known	28·00
Cadmium	Stromeyer, 1818	A metal resembling tin	55·74
Zinc	Parcelsus, 1550	Familiarly known	32·52
Hydrogen	Cavendish, 1776	Exists as a gas	1·00
Manganese	Chan and Scheele, 1774	Brittle metal of silvery color	27·67
Gold	Earliest ages	Familiarly known	98·33
Iridium	Tennent and Descotils, 1803	The hardest metal known	98·68
Rhodium	Wollaston, 1803		52·11
Platinum	Wood, 1741	Heaviest metal of silvery lustre	98·68
Palladium	Wollaston, 1803	Black powder	53·27
Mercury	Earliest ages	Familiarly known	100·07
Silver	" "	" "	108·00
Copper	" "	" "	31·66
Uranium	Klaproth, 1789	A metal, whilst immersed in water	60·00
Bismuth	Agricola, 1530	A brittle metal of silvery lustre	70·95
Tin	Earliest ages	Familiarly known	58·82
Lead	" "	" "	103·56
Zirconium	Berzelius, 1824	Of a crumbling texture, and gray color	33·62
Aluminum	Wohler, 1828	Obtainable in scales of the color of tin	13·69
Thorium	Berzelius, 1829	" as a heavy metallic powder	59·59
Glucinum	Wohler, 1828	" as a grayish black powder	26·50
Magnesium	Bussy, 1829	A brilliant silver-colored malleable metal	12·67
Calcium	Davy, 1807	A brittle white metal from lime-rocks	20·00
Strontium	" "	A heavy metal, readily oxydized	43·84
Barium	" "	A heavy metal, resembling cast-iron	68·64
Lithium	Arfwedson, 1818	A white metal like sodium	6·43
Sodium	Davy, 1807	A silvery metal obtainable from sea-salt	22·97
Potassium	" "	A silvery metal obtainable from potash	39·00
Erbium	Mosander, recently	Known as metallic oxides—rare	
Terbium	" "		
Ruthenium	Klaus, 1844	Obtainable as alloy of platinum	52·11
Pelopium	H. Rose, 1845	Very rare	
Niobium	" "		

NOTE.—The relative electro-dynamic conditions of the five last-named simple elements have not been as yet decisively ascertained.

RELATIVE PROPORTIONATE QUANTITIES OF THE SIXTY KINDS OF SIMPLE ELEMENTARY SUBSTANCES, OR GROUPINGS OF ATOMS REPRESENTING SIMPLE RADICALS.

More than one-half part of all the solid inorganic formations of the crust of our planet is composed of only two elementary substances, oxygen and silicium, variously grouped with all the other kinds of substances into the natural static condition of rocks, earths and metals; and eight-ninth parts of the fluid waters of all the oceans, lakes and rivers, are composed of the single element of oxygen. More than three-fourths of all the organic formations of vegetable and animal bodies are constituted also of only two kinds of elementary substances, oxygen and carbon. Thus the principal part of all the inorganic and organic formations of this planet are actually composed of various groupings of only three kinds of elementary substances, oxygen, silicium, and carbon; and the great mass of it is composed of only about fifteen kinds. The comparative quantities of some of the other kinds of elementary substances are so exceedingly minute, and rarely discoverable, that even experienced chemists have never had opportunities of seeing them. The most sagacious chemists can assign no important functions which they fulfil in the arrangements of the MECHANICS OF NATURE.

Of the preceding list of simple elementary substances, forty-eight are *metals*, and the remainder are denominate *non-metallic* substances; which are described in detail, with their several distinctive characteristic properties, in the popular treatises on chemistry. A review of them, prepared and designed to be here presented, is necessarily excluded as too voluminous to be embraced within our present plan.

VARIETY OF COMPOUND SUBSTANCES.

From the scanty number of the simple elementary substances which thus constitute the earth's surface, it might be supposed that an appearance of sameness of materials would meet our eyes in whatever direction we might turn them, like that of the monotonous elements of the expanse of the ocean. The silicium, or siliceous sands, indeed, do abound on some parts of the earth's surface, constituting uniform desert wastes; but the commingling of different groupings of atoms generally exhibits an almost infinite variety of forms, colors, hardness, solidity, fluidity, &c. Every difference of the relative proportionate parts of the groupings of different kinds of elementary substances, induces a distinctive difference in the resulting compounds.

In order to estimate the infinite variety of *compound substances* producible by the reciprocal combinations with each other of the different kinds of the above-named sixty classes of simple elementary atoms, we may have recourse to the arithmetical "Rules of Permutation," which demonstrate that only twelve letters of the alphabet admit of interchangeable arrangements in 479,001,600 different ways. But not only do the atoms of the several simple substances admit of one change of arrangement with each of the others, but most of them admit of three, four, up to six and seven different ratios of combining proportions.

Differences in the relative proportionate groupings of atoms of oxygen and carbon with lime, produce more than a hundred varieties of stony substances, as of marble, limestone, spars, &c., which are in appearance as unlike as if composed of entirely different kinds of elementary atoms.

With these differences of the interchangeable molecular arrangements of combining proportions of the sixty elementary substances, the varieties of the appearance of objects on the face of the earth become infinite, although the actual number of kinds of elementary atoms are so few. New compound substances are almost weekly discovered. The descriptive catalogue of such as have been deemed worthy of notice, has already been extended to 7000 in number, in a publication by Dr. Shaw, adapted for use by practical chemists; and in Gregory and Liebeg's edition of Turner's Chemistry, more than a thousand pages are appropriated to descriptive accounts of the various relative static and dynamic conditions of the interchangeable groupings of elementary atoms, with an account of their "behavior" during their change from one static condition of groupings to another. Fresh publications on chemical science are requisite every few years, to post up the recent acquisitions of knowledge; whilst old chemists are at a loss to comprehend new chemical nomenclatures consequent on subversions of successive chemical theories. The whole science of chemistry appears to be at the present time in an unsettled, transition state. In this uncertain condition it must continue to remain, until a definite plan or system of explaining the origin and modes of propagation of the impulses of mechanical force, denominated "chemical," is adopted as the fundamental basis of this branch of science.

ATOMIC WEIGHTS.

The ultimate atoms of all elementary substances being too minute to be appreciable in any way by human powers of perception, it may very rationally be asked, how are the weights of the ultimate atoms ascertained, as recorded in the last column of the preceding table?

We have supposed, that in the grouping of atoms into natural static conditions of inorganic and organic formations, the electrodynamic impulses are excited between individual atoms to aggregate them into magnitudes capable of being handled and weighed. Hence, by finding the relative proportionate weights of each kind of atoms in a mass, there is reason to suppose, that as the whole is made up of the parts, the relative weight of each component atom may bear the same proportion to their aggregate relative weights.

Taking water as an example: it is found by analysis that a mass of this fluid is composed of 8 parts by weight of oxygen, and of only one of hydrogen. Hence it has been concluded, that the atom of oxygen is 8 fold heavier than an atom of hydrogen.

To test this supposition, experiments have been made of causing a combination with this compound of water (oxygen 8, hydrogen 1, constituting oxide of hydrogen) of one more proportional part of oxygen. This may be artificially accomplished, so as to produce a new compound of water, with an excess of oxygen. The least excess that can be artificially added, reduces the atoms to the constrained static condition of grouping denoted by the chemical term "binoxide," or "peroxide," of hydrogen, the prefix to—"oxide"—being designed to denote a double dose of oxygen.

By now analyzing this water, which apparently exhibits all its former fluidity and characteristic appearances unchanged, it will be found that the quantity of oxygen obtainable will be just 16 fold, instead of 8 fold, the weight of the hydrogen. Hence this additional proof goes to confirm the fact, that two atoms of oxygen each weighs 8 fold of 1 atom of hydrogen.

The aggregate atomic weights of both kinds of atoms ($8+1=9$ and $16+1=17$) constitute the *chemical equivalents* of water, or oxide of hydrogen, 9, and of binoxide of hydrogen, 17.

The same system is extended to estimating the weights of all other simple atoms, as specified in the preceding table.

To ascertain the relative weights of atoms by a per centage scale, from the atomic or equivalent weights, requires the following calculation:

As the atom of hydrogen is only $\frac{1}{9}$ of the whole chemical equivalent, divide 100 by $9 = \frac{11.11}{100}$, very nearly, is the weight of the hydrogen in 100 ounces or pounds of water; by simply multiplying 11.11 by $8 = \frac{8880}{100}$, is found the weight of the oxygen in a per centage ratio.

As the volumes of space occupied by all kinds of matter are caused to be constantly fluctuating by changes of temperature, chemists have very rarely recourse to measuring or gauging the volumes of elementary atoms or masses in their calculation.

Although an elementary atom of hydrogen is estimated at only $\frac{1}{8}$ part of the weight of an atom of oxygen, yet it is found that it occupies double the quantity of space, whilst subjected to the pressure of atmosphere.

Hydrogen being found to be the lightest known substance, the weight of an individual atom of it has been adopted as an unit standard, or 1. It is not considered as having any determinate or appreciable weight taken absolutely by itself; but it is simply regarded as a comparative standard of the relative weights of all other kinds of atoms. An atom of the metal antimony is enrolled in the preceding table as 129 fold heavier than an atom of hydrogen; and so on with all the other kinds of elementary atoms.

It is very remarkable that no two kinds of elementary atoms are discovered to have exactly the same weight, or to exhibit precisely the same intensity of propagation of electro-dynamic action between their centres and that of the earth, if we except Rhodium and Ruthenium; and the identity in this case may probably be ascribed to the imperfectly examined constituent groupings of its atoms. Hence we are authorized to conclude, that this fact has some connections with the faculty of each kind of elementary atom to modify the propagation of electro-dynamic action between its own centre and that of the earth, representing the phenomenon of "weight."

Considering, then, that all human knowledge of atoms, as well as of the masses of elementary atoms, is derived from the groupings of such atoms into inorganic and organic formations by the continuous propagation of the electro-dynamic action of the sun, we shall proceed first to exhibit the facts of such mechanical groupings, and then the mechanical causes of them.

FACTS OF THE GROUPINGS OF ATOMS INTO SOLID STATIC CONDITIONS OF THE INORGANIC FORMATIONS OF CRYSTALS.

All kinds of elementary atoms are found to become naturally arranged into solid inorganic formations of crystals, each kind being grouped into particular angular shapes, which have served as characteristic properties to aid mineralogists and chemists to distinguish them from each other, like the particular shapes of different kinds of animals.

The shapes of crystaline formations being mechanical effects of the arrangements of atoms by the propagation of differently directed impulses of mechanical force, it hence follows as a logical deduction, that one of the principal standard tests adopted for judging of the different kinds of elementary atoms, is a powei of differently modifying the propagation of mechanical impulses at insensible distances between their respective centres.

By recourse to the highly magnifying powers of the solar microscope, the beautiful orderly manner in which the molecules become systematically grouped together during the process of the inorganic formation of crystals, presents an interesting spectacle, which every intelligent person may contemplate not only with instruction, but even with delight. The shadows of the moving molecules of various solutions of salts, placed on a pane of window-glass, are cast on a broad expanded sheet of canvas. On this white field they appear to move in regular ranks and files, like well-disciplined soldiers on a field of review, marching and counter-marching to form solid columns, each one starting forward in exact order, as if thoroughly drilled to comprehend not only its appropriate place, but even its appropriate time to move. No confusion or mistakes, like those so frequently observable in the irregular ranks of a militia muster, are observable. Indeed, exclamations of wonder are usually heard to burst forth involuntarily from the spectators, who for the first time witness this exciting spectacle of the movements of atoms during the process of crystalization, exhibited by means of the solar microscope.

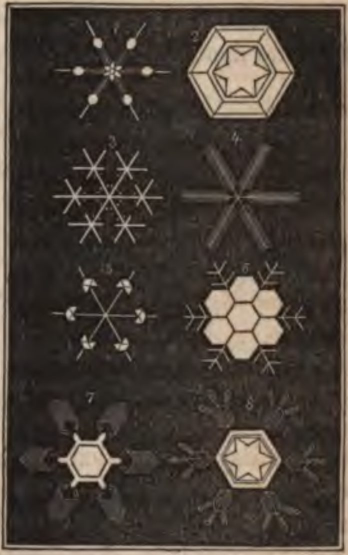
There is thus shown to be produced beautiful symmetrical shapes of crystals of hexagonal, octohedral, and other polygonal forms, with regular corresponding sides and angles, rivalling in precision and exactitude the artificial labors of a skilful lapidary. Every fragment of crystalline rock which we heedlessly tread upon, exhibits symmetrical angular arrangements of the component atoms, as if carefully cut and polished.

Silent and feeble as may appear to be the slight movements of atoms during their arrangement into groupings of crystals, yet there is actually exerted during this process an energetic action of physical force, which has been experimentally found to be adequate to rending asunder iron bombshells, during the freezing or crystalization of water inclosed in them. Even the iron bound chambers of massy pieces of artillery, which are designed to sustain the explosive action of gunpowder, and to project heavy missiles several miles from the cannon's mouth, have been rent asunder during the silent process of the crystalization of water confined within them.

There is thus demonstrable, experimentally, as admirable systematic regularity in the direction of the movements of all the minutest atoms of matter, as of the hugest masses constituting the worlds of the universe; accompanied also by an equally irresistible energy of impulses.

The most superficial observer becomes struck with admiration on surveying the brilliant specimens of crystals arranged on the shelves of a mineralogical cabinet. He realizes their powers of modifying the propagation of the electro-dynamic action of the sun to affect the material nerves of the eye with sensations recognized as the sparkling refractions of light, and of gorgeous hues of colors; whilst he admires the mathematical exactness of the corresponding equal sides and angles.

Fig. 5.



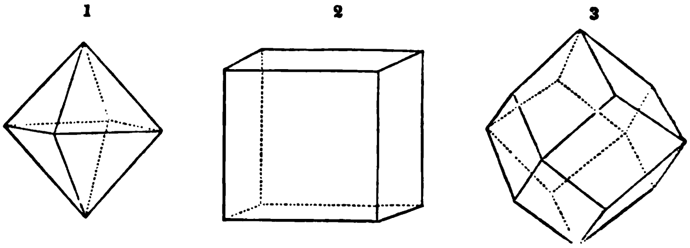
During an expedition to the polar regions, Captain Scoresby availed himself of the opportunity of examining microscopically the formations of crystals of snow. He has exhibited nearly a hundred different forms of these crystals; a few of which are shown in the annexed wood-cut. The forms of crystals of water, it will be noticed, are all arranged on a hexagonal system of angles.

The science of crystalography, like that of electro-dynamics, is of comparatively recent date. The celebrated Haüy, and Professor Weiss, first systematically established this branch of science, upon which volumes have subsequently been written. The latter writer has demonstrated that all crystaline forms may be brought under one of the six following shapes, which have been denominated "Systems of Crystalization."

1. The square or regular system of crystalization.
2. The square prismatic do. do.
3. The right do. do. do.
4. The oblique do. do. do.
5. The doubly oblique do. do.
6. The rhombohedral do. do.

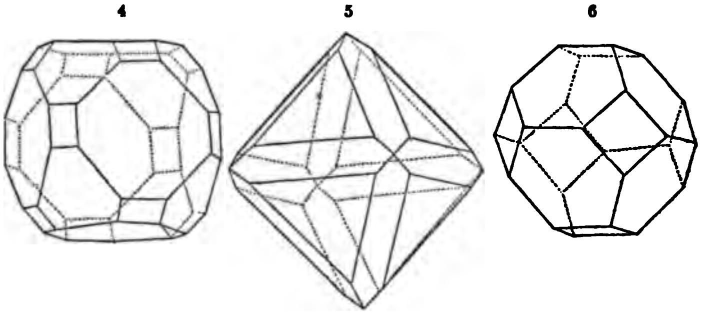
The crystals which have faces equal and similar to each other are denominated *simple*, as exhibited in the figures

Fig. 6.



Crystals which have at least two different arrangements of faces are denominated *compound.*

Fig 7.



Our limits will not admit of here showing the very great variety of the shapes of the groupings of atoms into the inorganic formations of crystals, which are made up of combinations of the preceding arrangements. The design in here introducing the regularity of the shapes of crystals, is merely to show that the symmetrical and beautiful arrangements of the groupings of atoms into static conditions of inorganic formations is a mechanical effect, produced and sustained by systematically directed and continuously propagated impulses of mechanical force.

The cause of this systematic excitation and continuous propagation of mechanical action will be considered, when we come to treat of the *dynamics* of the mechanics of nature, or Inorganic and Organic action.

DISTINCTIVE DIFFERENCES OF GROUPINGS OF ATOMS INTO THE STATIC CONDITIONS OF INORGANIC AND ORGANIC FORMATIONS.

There is a most remarkable peculiarity in the groupings of atoms of organic formations, which serves to distinguish them at a glance from the groupings of atoms of inorganic formations. The groupings produced by the agency of the organs of plants and of animals, are arranged in manifest accordance with some preconceived mechanical design of frameworks adapted for subserving special purposes of fixed habitations, or of locomotive mechanisms, of the various classes of animals and plants existing on the surface of this planet. On the contrary, the groupings of atoms of matter not produced by the agency of the organs of animals and plants, or all inorganic formations, although arranged with equal beauty of symmetrical forms in various angular crystals, exhibit a more simple plan of union, having relation only to the respective centres of the approximated atoms, without any other apparent design than that of subjecting such groupings of atoms to the action of natural forces established in connection therewith, to maintain the static conditions of solidity or crystalization.

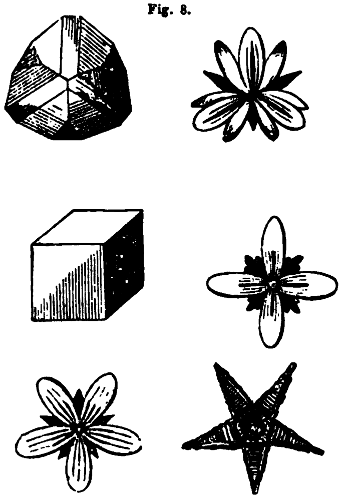
Naturalists have had recourse to similar observations of the symmetrical atomic groupings in the vegetable and animal bodies, and of the specific forces or powers innate or born in connection therewith, to determine the classifications of plants in the science of botany; and of animals, in the science of zoology.

The leaves and flowers of plants commonly appear arranged symmetrically into three or five equal sets of organizations, similarly sided, and regularly disposed. For instance, "the iris is formed with three straight petals, and three reflexed ones, alternately disposed; and the rose, with five equal and similar separate petals of the calyx, alternating with as many petals of the corolla."

The first figure represents the summit of a crystal as it appears to the eye, situated above it and looking down upon it; and the spaces, of various forms, diverging from this point, represent the symmetrical sloping sides of the crystal.

It may be noticed that this figure consists of three portions, exactly similar to each other; and that each part or member is repeated in *threes*, with similar faces and angles, displaying a regular "triangular symmetry."

Fig. 8.



A similar triangular symmetry is exhibited in the lily tribe of plants, the outlines of the flowers of which are displayed as counterparts of the crystals, to show their comparative general symmetry.

In the second set of figures there are *four* equal and similar portions, termed square, or tetragonal symmetry, having the cubical form of a common die. It is to be noticed, that a comparative similarity is established in the symmetrical arrangements of the inorganic atoms constituting the crystal, and the organized atoms constituting the flower.

The atoms of matter grouped into the crystals of common table-salt, and of yellow pyrites or bisulphuret of iron, frequently found imbedded in rocks, are perfectly arranged to form exact cubes, &c. At the depth of nearly 300 feet beneath the surface of the earth in a salt mine in Cheshire, England, I have extracted crystals so perfectly squared, as to rival the art of a lapidary to produce an equal symmetry of form.

In the next figure is represented a *five-sided*, or *pentagonal* symmetery of arrangement, frequently found in plants. This peculiar form is presented to observation both in the vegetable and animal kingdom, as well as in that of pentagonal crystals. The five fingers and toes of numerous species of animals exhibit this peculiar conformation; but the most perfectly exact pentagonal form in animal organizations occurs in the star-fish, abundantly found on the Atlantic shores of the United States. Various leaves and flowers exhibit this peculiar symmetry.

Elaborately symmetrical as are those groupings of atoms into crystals, they may be readily disintegrated and re-grouped, by the artificial propagation of electro-dynamic action.

The process of disintegrating the atoms of solid crystals of metals, salts, minerals, &c., and of re-grouping them into solid inorganic formations, is now practically accomplished as a business operation in the useful arts. Bars composed of solid crystals of silver, zinc, and other metals, are transferred, atom by atom, across an intervening freely movable fluid medium, to become re-crystalized, as by the processes of electro-silvering, electro-zincing, and other operations of *electro-metallurgy.* Thus by artificially modifying the directions of the propagation of electro-dynamic impulses, all the phenomena of the grouping of atoms into the solid *static* conditions of inorganic formations of crystals, admit of being readily accomplished at the pleasure of the operator, as we shall presently have occasion to show.

ON THE SIMILARITY OF FORMS AND OF CHEMICAL PROPERTIES, DEVELOPED BY GROUPINGS OF ATOMS INTO INORGANIC FORMATIONS OF CRYSTALS.

The grouping of different kinds of atoms into crystals of similar shapes, has been denominated by chemists, ISO-MORPHISM, from the Greek words ISOS, signifying *similar*, and MORPHOS—*form.* The atoms of carbon in the diamond, of sea-salt, of alum, and of arsenic, are all grouped into the same shape of octahedral crystals.

In accordance with the original law established by Mitscherlich, "isomorphism depends upon equality in the number of atoms of groupings, and similarity in their arrangement, without reference to their nature."

The similarity of the forms of bodies would apparently denote a similarity in other respects, as in the characteristic properties of cohesion, chemical affinity, &c.; but observation teaches us the fact, that although several different kinds of elementary atoms become arranged into corresponding similar forms of crystals, yet this correspondence does not extend beyond the mechanical arrangement of the atoms, in obedience to the polarization resulting from the electro-dynamic actions and reactions which have been recapitulated.

Certain different kinds of elementary atoms, when combined in the same proportions, and into the same cubical or other polygonally shaped crystals, may be made interchangeably to replace one another in component *equivalents*, without producing any alteration of the external shapes of the crystals; but it is found that the chemical properties of the crystals become essentially changed by every such transposition.

Hence it is inferred, that the difference of the shapes of crystals are simply indications of the result of a similar development of electro-dynamic impulses, in producing the relative mechanical arrangements of the atoms, without reference to the modification of the continuous propagation of such impulses to other approximated portions of matter.

It has been noticed by a distinguished chemist, "that it is certainly a truly remarkable fact, that the highly electro-negative chlorine, so opposed in its relations, as it usually appears to be, to the electro-positive hydrogen, should take its place without altering the characteristic properties of the compound. This would seem to indicate, contrary to what is generally seen in inorganic chemistry, that the chemical character of the compound does not depend so much on the nature of its elements, as on their arrangements or position in the compound."

If it be admitted, in the words above quoted, that the chemical character of the compound does not depend so much on the *nature* of its elements as on their *arrangement*, or relative positions in the compound, then we have no choice but to admit that the cause which produces the *chemical* character of compounds, must be identical with the cause that produces the *mechanical* arrangement, or groupings of their component atoms into crystals. This mechanical arrangement we have it in our power to produce and counteract at our pleasure, by the impulses of mechanical force, propagated in particular relative directions by means of electric matter. The final conclusion appears therefore unavoidable, that the chemical character of bodies is dependent on the disturbance of the electro-static condition of their component atoms, and on the resultant electro-mechanical forces thereby brought into action.

The arrangement of the atoms of manganese into crystals of a similar shape, when they become electro-dynamically united with the atoms of various other kinds of matter, constituting isomorphism, has been frequently a subject of remark by chemists. The form of the salt that is produced by the crystalization of manganese and oxygen, electro-dynamically united atom to atom, and constituting the compound termed the protoxide of manganese, presents the same appearance of angular structure with the salts of magnesia, "so that manganese belongs to and represents the *magnesian* family of elements." Manganese also similarly connects the sulphur family with the magnesian, by like forms of crystals of the sulphates and manganates; and thus, too, are selenium and tellurium, as well as sulphur, proved to be allied to the magnesian class, by sameness of the physical forms of their crystals. And as similar physical effects are produced by the same causes acting on matter, we may infer very naturally that these different families of atoms are similarly acted upon by electro-dynamic impulses developed between their respective centres.

It has been deemed by Professor Graham a very remarkable circumstance, that a single elementary atom of chlorine "should have the same value and character in combination with certain other kinds of substances, as two atoms of the several elementary substances manganese, zinc, sulphur, oxygen, hydrogen, &c. It suggests the idea that it is by the intimate association or conjunction of *two basyle atoms* that *one salt radical* molecule is produced; and, consequently, we may infer that the characteristic properties of the various salts do not originate from the absolute differences of the radical characters of the several elementary bodies constituting the bases, but rather from differences of the grouping of the atoms." As before stated, this difference of their grouping, exhibited by differences of the forms of their crystals, may be deemed to be a proof of variously modified impulses of electro-dynamic action, rather than of absolute differences of the nature of elementary atoms.

The atoms of carbon constituting a diamond, are grouped into regular octahedrons, and in graphite or plumbago, in six-sided plates. This difference of crystalization indicates a difference of the direction of the electro-mechanical impulses, which produce these different electro-mechanical effects of two shapes. Hence, carbon has been termed *dimorphous*, from the Greek word DIS-*twice*, and MORPHE, *shape*. Sulphur and the carbonate of lime exhibit also groupings of their atoms into two shapes.

No instance has yet been discovered where the same kinds of atoms have been grouped into three distinct forms of bodies, to entitle them to the appellation of "*trimorphous.*"

There are still other instances where two bodies are composed of the same proportions, or equivalents of the same kinds, of elementary substances; and yet they exhibit different characteristic properties. This occurs in the property of the colors of red and black sulphuret of mercury, which are composed of the same amounts of sulphur and mercury; and in the *yellow* and *red* iodide of mercury; the red rapidly turning to yellow on being "touched with a needle." This peculiar phenomenon has been termed ISOMERISM, from the Greek words ISOS, *similar*, and MEROS, *parts.*

In most isomeric bodies, it is supposed that the difference of properties is ascribable to a difference of the number of atoms in the mass of groupings, although the relative properties of each may be the same: as in

Oil of lemons,	10 carbon,	8 hydrogen.
Oil of turpentine,	20 "	16 "

The subject of the grouping of atoms into various inorganic and organic formations, as connected with the chemical properties developed by them, will presently come again under consideration, in illustrating the identity of chemical and electro-mechanical action.

THE SPHERICAL FORMS OF SOLID INORGANIC FORMATIONS OF PEBBLES, GRAVEL, AND SANDS, PRODUCED BY THE CONTINUOUS PROPAGATION OF THE ELECTRO-DYNAMIC ACTION OF THE SUN ON TERRESTRIAL MATTER.

From the facts that have been recapitulated of the continuous propagation of the electro-dynamic action of the sun between the centres of atoms at insensible distances, the result of an almost universal appearance of angular crystals might be anticipated to overspread the solid crust of the earth. This result does in reality occur throughout whole regions of country composed of strata of granite, quartz, lime-stone, feldspar, and other crystaline rocks. But there are very extensive regions of the earth's surface composed of smoothly-rounded pebble-stones and particles of gravel and sands.

A more palpable extent of impulses of mechanical force has been propagated by solar action to produce these mechanical effects of the attrition and disintegration of the angular crystals of the rocks of our planet, than in the grouping and maintenance of their component atoms into solid aggregations.

The process of the mechanical attrition of rounding angular points of crystalized masses into spherical forms of boulders, pebbles, gravel, and sands, is most impressively exhibited to the observer, who stands, during a storm, beneath a cliff overhanging the ocean, and watches the action of the waves. Fragments of the rocky cliffs are occasionally seen to become detached, and to fall into the ocean, where they are incessantly rolled over by the dashing and retreating surges, until they become chafed into spherical forms. The comminuted portions ground off from the angular points constitute the sands of the beach.

The intensity of the impulses propagated by the ocean-waves against solid bodies exposed thereto, has been ascertained by a dynamometer to be equal to a pressure of about three tons against each square foot of the exposed surface. The blocks of granite, and even massy iron cannons of the fortifications of Cherburg, in France, were piled together by the force of the waves during a storm.

The cause of the propagation of this vast extent of impulses of mechanical force is more readily traceable to the electro-dynamic action of the sun, through the medium of the fluid air and waters—of winds and waves—than in the silent propagation of impulses through the medium of fluid electric matter between atoms at insensible distances. Solar action on particles of air, as on particles of water, produces their separation from each other's centres, and a consequent occupancy of a greater volume of space, as popularly recognized by the term "rarefaction." The rarefied portions of the air ascend into the atmosphere, and the adjacent portions, in rushing forward to occupy their places, constitute the moving currents of air, or winds. The winds propagate the mechanical action to the surfaces of the great oceans, lashing them into foaming waves; and the latter are dashed continuously against the surrounding solid bodies fringing its shores.

A contemplative observer may sit by the sea-side to gaze for hours upon the sublime scene of the display of physical power exhibited by the huge rolling billows, which are dashed successively with thundering sounds, and flashing wreaths of spray, against the cliffs and beaches. Chafed and polished by attrition against each other, the rattling fragments of crystaline rocks become so perfectly rounded into beautifully smooth pebbles, as often to tempt the observer to select and retain one of them from the dominion of the waves.

These rounded boulders and pebbles are not confined to the locations of the present borders of the oceans. They are abundantly found far inland in the centres of the present continents of the earth's surface, and on mountain-tops, as well as in the depths of mines. This mechanical attrition of the ocean-waves on all parts of the crust of our planet, exposed thereto from mountain-peaks to their deep foundations, must have been going on during a lapse of time which human imagination falters in contemplating.

On examining huge masses of solid crystalized rocks on various parts of the earth's surface, these rounded and polished pebbles are discovered to be conglomerated and imbedded in them, like plums in a pudding, as denoted by the popular term of "pudding-stones." This fact proves that strata of the hardest rocks on the present surface of the earth are composed of these water-worn pebbles, cemented together into huge masses.

These indurated conglomerations of rounded pebbles are supposed by geologists to be antediluvian inorganic formations.

On breaking some of these smooth, water-worn pebbles, detached from conglomerate rocks, smaller pebbles are discovered to be imbedded in them—a rounded, water-worn pebble, within a rounded, water-worn pebble. On a sea-beach, beneath impending cliffs of conglomerate rocks, I have noticed, with the deepest interest, one of these compound conglomerate pebbles, rolled to and fro by the waves, and undergoing, for the third time, the process of becoming rounded by attrition to a spherical form.

Thus by tracing out these successive records of mechanical action, unmistakably engraved on every rounded pebble, there are to be discovered irresistible proofs of the almost infinitely continued propagation of the electro-dynamic action of the sun through the fluid medium of the winds, and of the waves of the sea—not only during the geological epoch of one antediluvian period, but at least through two or three such antediluvian epochs of inorganic formations.

It has frequently been attempted by geologists to establish some basis of calculation for estimating the age of our planet. The time required for great rivers in their flow to remove quantities of earth, and to accumulate them in alluvial deposits, forming deltas like those of the Mississippi, Ganges, &c., has been computed at nearly a hundred thousand years. The time required for the annual growth of the plants constituting the thick veins of mineral coal now buried beneath the earth's surface, has also been estimated. But all these modes yield in unmistakable certainty to estimates based on the extent of mechanical action propagated through the fluid medium of electric matter from the sun to the earth, and through the fluid medium of air and water, —the winds and waves—as above recapitulated, against the solid inorganic formation of rocks.

When we pick up a rounded pebble in our pathway, we are authorized philosophically to regard its spherical form as sculptured by the mechanical action propagated from the sun. And when we behold a mass of inorganic conglomerate rocks, now elevated above the level of the sea, we are as impressively taught to believe that the waves of ocean have for countless ages rolled over them, as to believe that ocean-waves have rolled over the sea-shells which stud the face of cliffs of limestone rocks. I have often been allured to take a seat beneath the mural fronts of these conglomerate rocks to study the appearance of a water-worn pebble imbedded as a constituent part of a larger water-worn pebble, in order to attempt to decipher their history in the hieroglyphic records of mechanical action impressed thereon.

With these data before him, one cannot restrain his reason from grasping series of hundreds of thousands of years for the age of our planet, and from musing on its past history, until he finds himself startled by the conviction of the truth of Professor Playfair's exclamation:—"How much further reason may go, than imagination may venture to follow!"

SOLID VEGETABLE ORGANIC FORMATIONS.

CONSTRAINED STATIC CONDITIONS OF GROUPINGS OF ATOMS INTO THE ORGANIC FORMATIONS OF VEGETABLE BODIES, PRODUCED BY THE ELECTRO-DYNAMIC ACTION OF THE SUN ON THE ORGANS OF PLANTS.

In treating of the grouping of atoms into the natural static conditions of FLUID FORMATIONS (page 28), it has been previously noticed, that water, air, and carbonic acid gas, serve to play a most important part in becoming modified, by the electro-dynamic action of the sun on the organs of plants, into various constrained static conditions of groupings of the organic formations of woody fibres, fruits, seeds, grains, and grasses, constituting *fuel and food;* and that hence the component elementary atoms of the atmosphere, and of water, have been termed the organic elements.

The necessity of the selection of these particular kinds of atoms to become incorporated into the organic formations of plants, has also been shown to be manifestly unavoidable, because plants are fastly rooted to one spot of earth, and cannot roam like animals from place to place in search of the kinds of groupings of substances adapted to serve as food, to become incorporated into their bodies. The above-mentioned fluids are in constant motion from the electro-dynamic action of the sun, and are wafted into contact with the organs of plants, thus furnishing to them their appropriate supply of food. This peculiar mode of the direct propagation of the electro-dynamic action of the sun upon fluid terrestrial matter, renders unnecessary the locomotive mechanisms of feet, fins, and wings in vegetable mechanisms.

Plants, as a class of living organic beings, exist more independently than animals, having their appropriate aliment supplied to them without the necessity of their roaming or toiling in pursuit of it. The lily is fed by the zephyr and dew-drop; and though it "toils not, neither does it spin," yet it gayly displays its beautiful organic formations of brilliant drapery, more gorgeously tinted with parti-colored dyes, than the kingly array of "Solomon in all his glory."

The chemical analysis of plants consequently shows that their organic structures are composed of the same kinds of elementary atoms as the atmosphere and water, viz.: OXYGEN and HYDROGEN—the elements of water; CARBON and NITROGEN—the elements floating in the atmosphere, being the *four organic elements.*

As water always contains in solution, whilst percolating the soil to the roots of plants, minute portions of lime, silicium, potash, ammonia, and some other kinds of elementary substances, it is usual to detect minute quantities of these particular kinds of substances in all vegetable organic formations.

The silicium and lime, or calcium, serve to give strength to the skeleton parts of plants; the groupings of the atoms of these substances becoming, in some cases, so solidly fixed on the exterior surface of the stems and trunks, as to strike fire with steel.

The establishment of life-power in connection with about half a dozen kinds of elementary atoms, grouped into the germs of innumerable different kinds of organic formations of the bodies of plants existing on the surface of our planet, appears to be ascribable to the determination of the absolute will of the First Cause; and consequently to be beyond the scope of the established laws of mechanical science. But observation teaches us that every movement and state of rest of the groupings of such elementary atoms, effected by the modifying agency of life-power in connection with the bodies of both plants and animals, are governed by established mechanical laws. These laws we shall now proceed to investigate,—not the immaterial principle of life-power.

The mechanical groupings of atoms into organic formations, like those of inorganic formations, are producible by the continuous propagation of the electro-dynamic action of the sun. It has been shown, that the solar influence reduces to a constrained static condition of stormy clouds in the sky the same molecules of water which are subsequently destined, in the falling rain-drop, to become incorporated into the constrained static condition of the organic formations of plants. The groupings of the molecules of water, in the one case, serve to modify the propagation of the electro-dynamic action of the sun to exhibit the inorganic formation of vapor. The mechanisms of the germ of plants, in the other case, serve to modify the propagation of the same electro-dynamic action to produce the organic formations of plants.

The occupancy of space by molecules of water in the form of vapory clouds in the sky, and in that of innumerable species of vegetable bodies on the surface of the earth, are antagonistical mechanical effects of the groupings of the molecules of water. Yet they both alike represent temporary constrained static conditions of groupings. The phenomena of electric flashes of light, heat, and impulses of mechanical force, are developed when the inorganic formations of vapory thunder-clouds recoil in the sky to their natural static condition of water; and precisely similar phenomena occur when all organic formations, popularly recognizable as fuel and food, recoil in the open air, or in furnaces, and lungs of animals; as will hereafter be more particularly demonstrated. The parallel appears to be complete, in this view of the mechanical functions developed by solar excitation, when modified by groupings of molecules into the inorganic formations of water, and into the organic formations of the germs of plants. But the propagation of the electro-dynamic action of the sun is modified to precisely opposite directions between the centres of the atoms at insensible distances in the two preceding cases. In the former, the atoms are urged asunder, and are caused to occupy 1700 fold more space in the inorganic formation of subtle fluid vapor. In the latter, they are reduced to fixed, solid organic formations. This fact very conclusively demonstrates, that the functions of the organs of plants are antagonistical to those of the simple elementary molecules of water, in modifying to opposite directions the impulses originating from the electro-dynamic action of the sun.

This illustration of the mechanical functions of the organic formations of plants exhibits in a true light the design of the creation of them as real mechanisms for modifying the propagation of the electro-dynamic action of the sun in various directions antagonistical to the inorganic formations of terrestrial matter. In this respect, the organs of living plants represent the mechanisms of galvanic batteries, in modifying the directions of electro-dynamic impulses, according to contingent circumstances,—antagonistically, or otherwise, to the same kind of impulses propagated between the centres of atoms of inorganic matter.

This propagation of electro-dynamic action through the modifying agency of the organs of plants, constitutes the Organic action, which produces the mechanical effects of the groupings of atoms into constrained static conditions of organic formations, constituting *fuel* and *food*, in contradistinction to Inorganic actions, which restores the same atoms to their natural static conditions. These will presently be separately considered, after taking a brief preliminary glance at the facts of the constrained static conditions of vegetable organic formations.

The original establishment of the existence of vegetable organic formations on the surface of our planet has been traced, by the Mosaic records, to "the creation" by a First Cause; but the number of species of plants, originally created, does not appear to be specified. Judging from petrified fossil vegetable remains, geologists have been led to suppose that, during a certain period of the antediluvian existence of the earth, there probably existed simultaneously only a few hundreds of species of plants. At the present day, rivers and ocean waters teem prolifically with countless varieties of species of vegetable organic formations.

A profound mystery hangs over the origin of the model germs of the different species of plants,—as inexplicable at the present day as at "the creation." There appears to be no possible mechanical explanation to account for the appearance in succession of various species of vegetable organic formations on specific portions of the earth's surface. In some cases, plants spring forth abundantly from the soil where no parent plants have been known previously to have existed. In the primeval forests of America, there is found to appear on spots of clearings, where whole hecatombs of trunks of timber trees have been rolled together and burnt, a spontaneous growth of luxuriant plants, which have received from the pioneers of these forests the descriptive name of "fire-weed," to denote its origin; as if, like the fabled phœnix, it originated from the glowing ashes. The appearance of crops of white clover, where ashes are strewn on virgin soils, has often caused the agriculturist to pause in his labors, and to muse upon this subject of the origin of the germs of plants.

Forests of oak and pine are found to succeed each other alternately on the same tracts of land, after one of the species has exclusively occupied the soil, and reigned predominant over the other for ages. The acorn is known to become speedily decomposed whilst subjected to the ordinary heat and moisture of a summer sky. There does not therefore appear to be a resuscitation of old germs; and we are consequently led to imagine some incomprehensible mode of the development of new ones, as has been stated to occur when the earth, excavated from mines and exposed to the sun, becomes covered with fresh plants. The spontaneous growth of seeds of minute vegetable formations, such as those of a luxuriant growth of mould on cheese, of fungi, &c., may familiarly excite wonder in the careful housewife, whose utmost efforts to prevent their growth often fail.

The electro-dynamic action of the sun may quicken, but it cannot create the germs. Mechanical science can only scrutinize the facts of these groupings of atoms into mechanisms, displaying exquisite skill in the structure of their delicate tissues, tasteful arrangements in their beautiful forms and gorgeous colors, and perfect science in their functions as elaborately designed mechanisms.

The first fact to be noticed in the development of organic formations, is the power denoted by the term "vitality," which has been defined by Liebig "to be the power which each germ possesses of reproducing itself." In investigating the principles of life, found to be *innate* in the seed-vessels of plants, it is also beyond the scope of mechanical science to trace out the mode in which the germs are successively produced by the agency of the organic formations of the parent plants, whilst excited by solar action. It is only possible to commence with the recognition of the fact, that in every kind of plant there is produced a sac or shell, containing a little farinaceous or sugary collection of elementary atoms of carbon, oxygen, hydrogen, and nitrogen.

Surrounded by this collection of these four kinds of elementary atoms, grouped together in various relative static conditions, is discoverable a minute arrangement of a portion of this collection of atoms into systematic shapes, exhibiting indistinct outlines of the forms of parts of a plant. This rudimentary nucleus has been denominated the embryo, or germ.

When this grouping of farinaceous atoms in the seed-vessels of plants is softened and rendered freely movable by moisture, the germs contained therein are found to become capable of modifying the propagation of the electro-dynamic action. They develope mechanical impulses adequate to moving, and re-arranging the groupings of the atoms, by which they are surrounded in the seed-vessel, so as to enlarge the germs into the distinctly shaped form of a "sprouting seed."

The manifest design of surrounding every germ with farinaceous groupings of atoms of carbon, hydrogen, oxygen and nitrogen, in the seed-vessel, is to furnish it with materials ready at hand, to become remodelled into the mechanism of a nascent living plant. Were not this little store of materials thus furnished to the living germ, and carefully inclosed with it in the seed-vessel, as if by the provident care and foresight of the parent plant, the originally feeble powers of the offspring would have within its immediate reach no suitable materials to become assimilated, for the enlargement of its organs, to the due degree of development necessary for constituting a new mechanism. This new mechanism, thus aided, speedily becomes independently capable of modifying the propagations of the electro-dynamic action of the sun, to collect more of the same kinds of elementary atoms from the surrounding air, water, and earth.

The gradual augmentation of the intensity of solar excitation in the vernal season of the temperate zones, produces this springing forth of the germs. From this modification of the electro-dynamic action of the sun in the form of organic action, this season has received its poetically emblematic name of "the Spring." At this season the variegated drapery of blossoms and flowers first appear pendent from every stem, flashing in the sunbeams with bright colors of purple, scarlet, and gold, as if they constituted so many beautifully painted banners, rejoicingly displayed in honor of the birthday of every newborn germ.

It appears to be the sole and unceasing effort of every plant, during the whole period of the vigor of its life, to collect these little provisionary stores of farinaceous food within the seed-vessels containing the germ, to which it has given birth; as if it were really indued with the intelligent forecast of a provident parent in anticipating the future wants of their newly-born offspring. There is found to be just enough of this little store of appropriate food collected in each seed-vessel, to last until the developing organs of the young plant become sufficiently enlarged and vigorous to gain, independently, their supplies of appropriate food from the carbonic acid gas and water, that is brought within the reach of their leaves by the winds and rains, and by the decomposing soils, or humus, in contact with the roots.

In the development of an embryo germ, a portion of the farina, by which it is surrounded in the sac or seed-vessel, is found to recoil from this temporary, constrained, static condition, to its natural static condition of carbonic acid gas and water, and to propagate electro-dynamic excitation of heat in the modified form of fermentation.

Observations of the process of germination teach us that a fermentation of the farinaceous matter of the seed-vessels is first caused to commence by the propagation of the solar influence, thereby augmenting the excitation of the heat necessary for the quickening of the organs of the germ. At the same moment there is presented to them the decomposing particles of farina, in the fluid, plastic form of the nascent carbonic acid gas. In this peculiar state, the organs of the germ are enabled to select and group together, into modified organic formations, the little store of surrounding elementary substances, which thus practically subserve the purposes of both fuel and food, to excite and sustain the feeble powers of vitality in the embryo offspring.

A similar process of germination is artificially resorted to by brewers in the process of the malting of barley. By first inducing excitation of artificial heat in the moistened grains, the phenomenon of the fermentation commences, accompanied by the spontaneous excitation of heat, and of simultaneous organic action, producing a movement of the sprouting germ, which issues from one end of each grain. The organic action is thus exerted to produce the effect of the reorganization of a portion of the farinaceous carbon, and also of the dynamic movements of the rambling rootlet.

The mechanisms of the embryo organs of plants are unable to modify the propagation of the electro-dynamic action of the sun with sufficient energy to transmute the hard, solid farina of the seed-vessel directly into the parts of a new plant, unless an incipient stage of fermentation first take place, to relax the intensity of the previously-established organic action that sustains the grouping of the farina in the solid condition of an organic formation. Even the mechanism of the vigorous organs of the animal stomach are not adequate to overpowering the organic forces established in the groupings of the atoms of the four organic elements into the seeds and grains containing the living, embryo germs, which are found to pass unchanged through the digestive organs. For this philosophical reason, the preliminary process of comminution with the teeth, or with gravel stones in the gizzards of fowls, &c., is necessary. The artificial grinding and crushing of grains of wheat, and of other farinaceous seeds, has been practised from the earliest dates of the history of the human race, in accordance with this principle.

There appears also to be the same good philosophical reason for fermenting, as for grinding, the farinaceous grains used as food by man and other animals. The *raising* of *bread* is in fact an exact artificial imitation of the natural preparation of the same materials, when they are consumed as food by the embryo plant. The increasing warmth of a vernal sun, and the moistening of vernal showers, induces a preliminary stage of fermenation, during the relaxing inorganic action of which, the reorganization and regrouping of the atoms are more readily accomplished by the organs of the plants; and doubtlessly the same reason applies to the reorganization of the same farinaceous materials into the bodies of human beings. Hence we infer that the modern process of introducing bubbles of carbonic acid gas into the texture of bread, by means of commingling acids and alkalis, must be essentially unphilosophical.

But even this imitation of light bread may be deemed to be far preferable to over-fermented bread. Bakers very commonly allow the process of fermentation of bread to proceed to the acetous stage, for the purpose of gratifying the cupidity of customers, who prefer a big loaf to a healthful one.

When the process of fermentation has passed from the incipient to the second stage of acetous fermentation, the organic functions of digestion of persons of sedentary habits are inadequate to arresting and overpowering the inorganic action thus artificially induced in a mass of food; and the pernicious results are felt in the impaired tone of the animal system. Many really pious patients may ignorantly ascribe this, among other "ills that flesh is heir to," to the dispensations of Divine Providence, instead of the dispensations from the kneading-trough of the baker.

A degree of instinctive intelligence is implanted, or innate in the mechanisms of plants, which serves to govern the direction of the organic actions in the due performance of their functions. The roots become developed beneath the surface of the earth with a manifest display of sagacity for accomplishing in the most successful manner the design of searching for the several kinds of grouping of alimentary atoms. The roots penetrate the soil to remote distances in directions where their supply of food is located, in despite of obstacles which seemingly might have deterred their progress. I once had an opportunity of noticing roots of willow trees, which had penetrated under the deeply laid foundations of a church, and to a considerable distance through the dry earth beneath the floor, to reach the buried bodies there interred. The very cavities of the bones and skulls, as well as the surfaces of them, were searchingly pervaded by a network of tissues of the fibrous roots, which were apparently feasting upon the remains that the worms had spared.

In decayed wooden pipes of aqueducts, I have noticed that a small orifice of the size of a large pin-head afforded ingress for roots sufficient to occupy the entire cavity of the bore for many feet, so as effectually to impede the flow of the water. The roots projecting from the stalks of the Indian corn and sugar-cane descend from the joints above the earth's surface, and penetrate beneath it, as if purposely for bracing the lofty stalks, as shrouds support the masts of vessels reeling in a gale. In exposed positions on hill-tops, the roots of large trees branch off from the trunks, with the scientific design of more strongly bracing against the powerful impulses of blasts of wind, which might otherwise prostrate them.

The preceding phenomena may be deemed to be the result rather of statical organic functions, than dynamical organic action; but there are instances in which real dynamic impulses of organic forces are brought into action through the modifying agency of the organs of plants, such as are exhihited in the violent projection of seeds from the seed-vessels of certain plants, as the balsamine, for the purpose of disseminating them to a distance from the parent stem. Indeed, there is one kind of plant which performs the part of an assassin or executioner, by opening its petals invitingly, to induce flies or other insects to alight upon its bosom. At the first touch of the adventurous explorers, the plant suddenly clasps them within the contracting petals, as if by the spring of an artificial trap, and holds them fast in an embrace, from which they find no release except in death.

This fact discloses a degree of sensitiveness and motive power, like that transmitted by the nerves and muscles of animal bodies. One species of plant has actually received the popular cognomen of the "sensitive plant," from the sudden contraction and closing of its leaves at the slightest touch; as if it were really endued not only with sensibility, but also with the power of controlling dynamic forces.

There is developed no inconsiderable vegetable motive power by the germs of plants in pushing downward their roots into the tough soils beneath them, and in upheaving the clods that obstruct the ascent of the stems to receive the exciting action of the solar influence. I have noticed a clod of earth, of the weight of many pounds, to be uplifted by the combined impulses exerted by a number of germs in the process of sprouting.

After the first stage of dependent germination is completed, the newly developed organs of roots and leaves, subjected to the excitation of solar action, exert the extraordinary power of decomposing carbonic acid gas, retaining the atoms of carbon, and rejecting those of oxygen from the pores of the leaves. The plant now becomes an independent, living being, capable of supporting itself by the aid of the continuous excitation of the sun, gaining its food in the grouping of elementary atoms of carbonic acid gas diffused in the atmosphere and soils, and in the hydrogen and oxygen of rain-water.

It has been demonstrated by the experiments of Pouillet, that during the process of vegetation, electricity is constantly excited from all vegetating plants. The electro-dynamic action of the sun on molecules of water has been shown to be one of the most efficient causes of the disturbance of the electro-static conditions of the matter of the surface of our earth. The additional fact that water is decomposed into its elementary conditions of hydrogen and oxygen, and solidified into the fixed component elements of various kinds of wood and other vegetable organizations, is sufficient to convince us, that electricity must be actively excited, and a consequent impulse of electro-mechanical forces developed, during germination.

Becquerel states that electric currents may be actually detected between the parts about the stems and opposite parts of various kinds of fruits. In a recent publication it has been stated, that certain vegetable organizations, such as the marigold, orange-lily, monk's hood, and Indian pink, "emit, at intervals of several minutes, two or three flashes of light, in quick succession; and when several flowers in the same place emitted their light together, it could be seen at a considerable distance." This phenomenon was noticed in July and August, when the sky was clear.

The preceding details of the groupings of atoms into the constrained static condition of vegetable organic formations, have been introduced in these researches into the originating causes of motive power, for the special purpose of exhibiting the important functions which they perform in the mechanics of Nature, in the modified forms of FUEL and FOOD.

FUEL AND FOOD, CONSIDERED AS CONSTITUTED OF GROUPINGS OF ATOMS REDUCED FROM THEIR NATURAL STATIC CONDITIONS OF WATER AND CARBONIC ACID GAS, TO CONSTRAINED STATIC CONDITIONS OF VEGETABLE ORGANIC FORMATIONS.

The preceding investigations have exhibited the organs of plants as mechanisms, designed for performing the functions of modifying the directions of the propagation of electro-dynamic impulses, antagonistically to the directions of the same impulses when modified by the sixty different kinds of groupings of the simple elementary substances. The propagation of this electro-dynamic action, when modified by the mechanisms of the organs of plants, represents Organic Action; and when modified by the sixty different kinds of groupings of the simple elementary substances, it constitutes Inorganic Action. The Organic action, when paramount, reduces the atoms of carbonic acid gas and water from their natural static conditions to the constrained static conditions of groupings of vegetable organic formations; the Inorganic action, when in turn it becomes paramount, restores these constrained static conditions of groupings of organic formations to their natural static conditions of carbonic acid gas and water. The former mechanical process is denominated "organization;" the latter, "disorganization." The propagation of the electro-dynamic action of the sun in the former case is denoted by the term "germination;" in the latter, by the various terms of "fermentation," "combustion," and "chemical decompositions."

When the groupings of atoms of organic formations are employed in furnaces to undergo the process of recoiling to their natural static condition of carbonic acid gas and water, by the process of combustion in furnaces and boilers of locomotive engines, they are regarded as FUEL; and when similarly employed to undergo the process of combustion in the lungs of living animal mechanisms, they are regarded as FOOD. The change of the groupings of atoms from their constrained static conditions of fuel to their natural static conditions of groupings of carbonic acid gas and water, propagates dynamic impulses of inorganic reaction artificially available in the modified form of "steam-power." The recoil of groupings of atoms of organic formations constituting food, serves to propagate dynamic impulses of inorganic reaction, naturally available in the modified form of "animal motive power."

This view of the functions of the groupings of atoms into the organs of plants, exhibits them distinctly as real mechanisms, scientifically devised for modifying the propagation of the electro-dynamic action of the sun antagonistically to the propagation of the same electro-dynamic action by the sixty different kinds of groupings of the simple, elementary substances. A more intense electro-dynamic action of the sun must be propagated through the groupings of atoms of the organs of plants, to counterbalance and overpower the same electro-dynamic action, when antagonistically propagated through the agency of the groupings of the sixty inorganic simple elementary substances. An equally intense electro-dynamic reaction must become developed when the Inorganic action in turn recoils and overpowers the Organic action.

In the philosophy of the Mechanics of Nature, we are therefore authorized to consider all Inorganic and Organic Formations as representing actual static conditions of terrestrial matter, sustained by oppositely-directed impulses, modified by the groupings of atoms into mechanisms of the organs of many thousands of plants on the one hand, and by the groupings of atoms into the mechanisms of about sixty simple elementary substances on the other.

In accordance with the well established laws of mechanical science, in every case of the disturbance of counterbalanced forces, a resultant dynamic action must unavoidably become developed. When, therefore, constrained, temporary groupings of atoms of organic formations are restored to their natural, permanent conditions of groupings, a resultant electro-dynamic action must necessarily become developed, and propagated to surrounding bodies. These principles lead us to regard all organic formations of FUEL as constrained groupings of atoms, embodying statically counterbalanced impulses of Organic action and Inorganic reaction. The organic formations of fuel, therefore, represent constrained, bended springs, deflected by Organic action, and caused to recoil by the antagonistical impulses of Inorganic reaction. In this respect they may be deemed *reservoirs of sun-power.*

Facts, almost daily brought to light by geological explorations, demonstrate, that the main purpose to which the surface of this planet was appropriated, during a period of countless ages after it was subjected to the electro-dynamic action of the sun, was the reduction of elementary atoms of carbon from the invisible, fluid form of carbonic acid gas, into the solid bodies or organic formations of plants. Only a few animals of the alligator or Saurian race appear, from organic remains discovered, to have once occupied the earth, and to have basked in the sunshine and floundered in the wide-spread, peaty marshes.

With these most remarkable facts presented for our consideration, we cannot but pause to reflect on the reasons for which the surface of our planet was left in a cheerless state, unoccupied by intelligent beings, during the vast period of time, which distinguishes its antediluvian history by no other important memorial than that of the designation of the "CARBONIFEROUS PERIOD" of the existence of the earth.

To this subject we shall presently have occasion to recur, in order to explain the apparent mystery connected with most important ultimate designs relating to the future dynamic history of the occupation of the earth by finite, intelligent beings, capable of rendering the electro-dynamic action of antediluvian sunshine available as a source of light, heat, and steam-power.

The term "carboniferous," or carbon-producing, as applied to plants, is to be understood as implying the power or faculty of collecting the atoms of carbon brought into contact with the organs of plants—not that of producing carbon, as this term might seem to imply.

Vast deposits of mineral coal, subserving the purpose of fuel, are now found securely buried beneath the cold wet strata of the earth. There is no more doubt about the vegetable origin of these groupings of atoms of carbon into mineral coal, than of the origin of the wood-piles stored up in a modern farm-yard; for the fibrous and porous texture of the wood is distinctly discoverable by the microscope, on scrutinizing specimens of this mineral. But it has sorely perplexed geologists to account for the mode in which the antediluvian surface of the earth, after having been exposed to the electro-dynamic action of the sun, and after maturing the crops of organic formations of peat-bogs, has become turned under, like a corn cake, after one side is done.

The tracts of country, beneath which these deposits of mineral coal are found, are designated by miners "coal-fields," as containing these antediluvian crops of vegetable organic formations, securely harvested and housed for the use of man. The antediluvian sunshine has been as usefully expended in maturing harvests of fuel for human advantage, as the sunshine of the present day in causing the forests of the earth to bud, and put forth their branches.

The ultimate designs of the accumulation of the organic formations of fuel mineral coal on this planet, before the occupancy of its surface by man, will presently be reverted to, after taking a preliminary view of the facts of the mechanical groupings of atoms into the constrained static conditions of groupings constituting fuel and food.

The following table exhibits an interesting comparative view of the relative proportionate quantities (by weight) of the several kinds of atoms, which are actually collected by the agency of the organs of living plants, whilst excited by solar action; and which are moulded thereby into the various constrained static conditions of the vegetable organic formations of wood, peat, coal, &c., serving as *fuel;* and of the nutritious matter of seed vessels, grasses, fruits, &c., serving as *food.*

TABLE OF ORGANIC FORMATIONS OF FUEL AND FOOD.

Relative proportionate weights of different kinds of Elementary Atoms, reduced to the constrained static conditions of Fuel and Food, by the electro-dynamic action of the Sun on the organs of plants.

VEGETABLE ORGANIC FORMATIONS.	BY WEIGHT.				
	CARBON.	HYDROGN.	OXYGEN.	NITROGEN	ASHES.
Anthracite Coal	89·	3·	4·	1·00	3·
Bituminous Coal	75·	6·25	12 50	6·25	
Wood or Lignin	50·	5·	42·		3·00
Wheat	46·10	5·80	43·04	2·03	2·04
Rye	46·20	5·60	44·20	1·70	2·30
Oats	50·70	6·40	36·70	2·20	4·00
Rye Straw	49·90	5·60	40.60	0·03	3·60
Potatoes (dried)	44·	5·80	44.70	1·50	4·00
Turnips	42·90	5·50	42·30	1·70	7·60
Dry Hay	48·87	5·76	39·71	1·84	6·82
Pure Sugar	42·85	6·35	50·08		
" Wheat Starch	43·55	6·77	49·68		
Gum-arabic	42·23	6·93	50·84		
Olive Oil	77·21	13·36	9·47		
Turpentine do.	88·46	11·54			
India Rubber	90·	9·12	·88		
Camphor	79·28	10·36	10·36		
ANIMAL ORGANIC FORMATIONS.					
Fibrine, or Blood and Muscles	53·	7·	20·		20·
Human Fat	79·	11·	10·		
Hogs' "	79·	11·	10·		
Whale "	79·	11·	9·		

By scrutinizing the details of the preceding table of the relative proportionate parts of the four kinds of elementary atoms grouped into the organic formations of wood, or lignin, constituting the substance usually burnt as *fuel*, and of hay, of grains of wheat, rye, &c., constituting the *food* of animals, it appears that about one-half part of the weight of all of them is composed of atoms of carbon or charcoal. Most of the remaining part is composed of the atoms of hydrogen and oxygen, in very nearly the same relative proportions which constitute water. As these four kinds of elementary atoms are invariably found to compose the bodies of plants, it follows, of course, that the growth of plants must essentially depend on the ready supply of these kinds of atoms as their appropriate food, combined with a due degree of the excitation of the sun. In proportion to the abundant supply of the preceding materials of carbonic acid gas and water to the modifying agency of the organs of plants, whilst excited by the electro-dynamic action of the sun, we shall now proceed to show that the production of organic formations takes place on the surface of the planet, on which man also finds himself existing as a wonderful organic formation.

By critical examinations of specimens of the air of the atmosphere, collected at various heights above the earth's surface, chemical tests have demonstrated that there is distributed very uniformly throughout the whole extent of the atmosphere, about $\frac{1}{2000}$ part of its weight of carbonic acid gas. By analyzing this gas, its constituent elementary atoms have been found to consist of 6 parts by weight of invisible transparent carbon, and 16 parts by weight of equally invisible atoms of oxygen.

Small as this portion of carbonic acid gas may appear to be, yet, were it collected on the earth's surface, the aggregate quantity would form a substratum of pure gas fifteen or twenty feet in depth. Estimates have been made to show the probability of the existence of as much of this fluid carbon diffused in the atmosphere in the natural static condition of carbonic acid gas above the earth's surface, as there exists of solid carbon buried beneath the earth's surface.

The presence of this carbonic acid gas imparts to common well-water a brisk, agreeable taste; and to soda-water, champagne, beer, &c., the sparkling and the pungency, which render these beverages peculiarly palatable.

Observation teaches us that carbonic acid gas becomes naturally united with molecules of *cold* water, and naturally separated as the water becomes *warm*. This fact is familiarly exhibited when cold water is drawn from a well, and exposed in a glass to the warm air of a room. The interior of the glass becomes lined with it, in the form of a coating of small air-bubbles. This simple fact involves the most momentous consequences of the development of vegetable Organic formations.

When the molecules of water are lifted by the electro-dynamic action of the sun to the upper regions of the air, in the form of steamy vapors or clouds, they there become cooled, and condensed into cold water, and often frozen into icy particles of hail, even in midsummer. In this cold state, the drops of falling rain become united with the atoms of carbonic acid gas floating in the atmosphere, and bring them by their descent, to the surface of the earth, and beneath the earth's surface. Hence every shower transports carbonic acid gas to the roots of plants; and every movement of the air transports the same gas into contact with the expanded leaves.

Numerous carefully conducted experiments have verified the fact, that whilst living plants are exposed to the electro-dynamic action of the sun, the atoms of carbonic acid gas are drawn into the porous organs of the leaves and roots. The carbon is there separated from its combination with the atoms of oxygen, and assimilated into the solid organic vegetable formations; whilst the atoms of oxygen are rejected in a pure state. The same vegetable organs are also capable of reducing combined atoms of oxygen and hydrogen from their natural fluid static conditions of water, to solid parts of vegetable bodies.

Experiments in the laboratory of the chemist demonstrate, that it requires intense mechanical action of compression of more than 500 pounds to the square inch of surface, to reduce carbonic acid gas from the natural static condition of an invisible air, to that of a constrained condition of groupings of a visible liquid, or solid inorganic formations of snow-white crystals. And the application of the most intense mechanical compression available by the power of man, has never yet reduced the atoms of nitrogen, The sea in these regions appeared quickened into life by the abundance of minute animalculæ, who collect and feed upon the equally minute aquatic plants, and re-organize them into their bodies.

The comparative available supply of organic carbon of these sea-plants even exceeds that which is matured in most of the plants existing beneath a vertical sun. Several kinds of seaweeds are eaten as nourishing food by mankind, such as the Irish moss. It is stated that, in the Shetland Isles, the cattle are driven down to the shore, at the recess of the tide, to partake of the abundance of this nutritious food.

This remarkable prolificness, in inorganic formations, of the apparently inhospitable Polar seas, has often been a theme of wonder to naturalists. It has been deemed an inexplicable phenomenon, that the cold sea water should be quickened with vegetable and animal life, where it might be supposed that a slow and sparse extension of vegetable organic formations might be anticipated, from the feeble electro-dynamic action of the sun during the long day of a Polar summer. This subject I have not found noticed; and it will be here investigated as particularly fraught with instruction in illustrating our present subject of the rapid reduction of the atoms of carbonic acid gas and water, from their natural static conditions of groupings, into the constrained static conditions of groupings of vegetable organic formations, constituting the *food* of animals, and the subsequent development of animal motive power during the recoil of these groupings to their original natural static conditions.

The preceding phenomena of the rapid growth of algæ, or seaweeds, in icy waters, demonstrate conclusively that organic life depends on the propagation of the electro-dynamic action of the sun in combination with the presence of an abundance of carbonic acid gas—the food of plants—which exists in water of a cold temperature. Water, at the freezing point, is found to be capable of retaining more than its own volume of carbonic acid gas, and more than twice the quantity which the same water will contain when heated to the boiling point. A given quantity of carbonic acid gas also expands in volume more than 50 per cent. on passing from a temperature of 32° to that of 86° Fahr., the heat most favorable to the growth of cereal plants. Consequently, there are double the number of atoms of carbon in the same volume of carbonic acid gas at the former temperature that there is at the latter temperature. As plants derive their supply of carbon from the decomposition of carbonic acid gas, it is hence manifest that their appropriate food is much more abundantly supplied to them in the cold water of the icy seas, than it is in the warmer water of the tropical seas, or in the warmer atmospheric air of the temperate zones, which contains only $\frac{1}{2500}$ part of the gas.

It may probably be ascribed to this very fact of the evolution of an extraordinary quantity of carbonic acid gas by the water in the cold wet earth about the roots of plants, on being first warmed by the heat of a vernal sun, that the principal part of the growth of trees in temperate climates takes place early in the spring of the year.

Again, it may be calculated that whilst there exists this extraordinary abundance of carbonic acid gas in the icy polar seas, the fact is experimentally established, that at the temperature of freezing water, this gas admits of being reduced from its natural *aeriform* static condition to a *liquid* state, by a mechanical action equivalent to a pressure of 313 pounds to the square inch of the surface of the gas inclosed in the cylinder beneath a forcing piston. Whereas at the warmer temperature of 100° of Fahr., the average degree of heat excited by the direct electro-dynamic action of the sun in equatorial climes, a mechanical action equivalent to a pressure of 935 pounds to the square, is found to be requisite to produce the same result of the condensation of carbonic acid gas. This fact demonstrates that a three-fold greater mechanical force is requisite to reduce this gas from its natural static condition to a constrained static condition at the temperature of the sea water in the torrid zone than at the frigid zones.

This great mechanical advantage facilitates the condensation of carbonic acid gas by the organs of plants in the cold waters of the icy seas, and affords an explanation of the phenomenon of the fertility of the arctic and antarctic oceans, and for the teeming of those inhospitable regions with vegetable and animal life. It is not "the cold water" which the marine animalculæ prefer," as supposed by Captain Ross; but rather, the more abundant supply of vegetable organic formations of food, which they find to be most prolifically abundant in cold water.

Sufficient evidences have now been adduced to demonstrate that the electro-dynamic action of the sun is not fruitlessly expended even on the cold water of polar seas, and amid icebergs, during the long day of ceaseless splendor of an arctic and antarctic summer; but, on the contrary, through the agency of the mechanisms of numerous species of algæ, this electro-dynamic action is propagated productively of groupings of atoms of carbonic acid gas and water into vegetable organic formations serving as food for animalculæ, which are eaten, and become reorganized into the bodies of larger animalculæ. These serve in turn as food to become reorganized into still grosser sea insects, fishes, seals, &c. And these also finally serve as organic formations of food to polar bears, to the huge walrus, and whale. The most bountiful supplies of aliment become reorganized into fat, blubber, and oil, amid icebergs, where the most profuse combustion of these organic formations is required in the lungs, to sustain animal heat and animal motive power.

From the polar sea of Baffin's Bay there is found to flow forth across the Banks of Newfoundland, a continuous current of cold water, bearing along numerous icebergs, together with these teeming myriads of living organic formations of marine animals. Here the codfish resort to feed upon these marine animals. And, finally, here also men resort to catch the codfish, for supplying food to the nations inhabiting the adjacent shores. The bark of the adventurous whaler is boldly navigated even amid towering icebergs, to plunge the harpoon into the huge whales, whose accumulations of oil serve to supply the lamps employed to propagate the electro-dynamic action of the sun incident on the polar regions, to brighten the gloom of night in more southern climes, and to cheer the evening firesides of the inhabitants of populous cities.

This fact of the presence of a greater quantity of carbonic acid gas in cold water than in tepid water, may have also an important influence in the organic formations and durability of the vast ranges of coral reefs and islands in the tropical seas. As the presence of carbonic acid gas in water serves to dissolve limestone, so the escape of this gas from water serves to deposit lime from its solutions. Were the same proportionate excess of this gas to prevail in the waters of broad seas, spread out beneath a vertical sun, as is present in the cold waters of the polar seas, the coral formations might become dissolved thereby as fast as they are formed by the labors of the untiring architects, who rear these stupendous structures from the bottom of the sea.

By the preceding principles peculiar facilities are afforded to the animal mechanism of coralline insects to organize the vast extent of the formations of coral reefs in tropical oceans.

In surveying the various static conditions of groupings of atoms into a species of half vegetable, and half animal organic formations—eating food like animals, and rooted to one spot like plants—we have to notice the very extensive and interesting class of *Zoöphytes*, which derive their name from the Greek words ZOÖN, *animal*, and PHUTON, *plant*, denoting an "animal plant."

This class of organic formations are attached to the rocks at the bottom of the sea, like rooted vegetables, and possess no more power of locomotion than is sufficient to thrust their heads and arms out of their stone doorways, to seize the food that drifts past them. They fulfil all their limited functions of vitality without a heart, or system of circulation, and without distinctive sexual organs. They propagate like the vegetation of which they are the copies, by budding forth from various parts of the parent stem. Bud is protruded beyond bud, until the continuous aggregations become huge extents of organic formations of coral rocks.

Vast formations of coral rocks are found extended in reefs stretching thousands of miles in the tropical seas, and even rising above the surface of the waves, to form large islands. The fragments of these rocks, pulverized by the incessant lashings of their mural fronts exposed to the surges, commingled with sand, are accumulated on the surface of them, forming a fruitful soil. The cocoa-nut, with its husk adapted for navigation, is wafted to these islands, and cast thereon by the foaming breakers. Man next resorts to them, and erects his habitation on foundations of adamantine rocks, that are organized in mid-ocean by feeble worms, whose conjoint labors have produced structures that render comparatively insignificant the greatest works of the human species. On some of the groups of coral islands, visited by the United States Exploring Expedition, it has been stated that more than thirty thousand inhabitants subsist. Even a portion of territory of the United States has been reclaimed from ocean by the coral worms, as appears by the opinion of Professor Agassiz. He considers the peninsula of Florida, up to the level of the surface of the surrounding waters, to be based upon the organic formations of coral rocks. A large portion of the valley of the Mississippi is based on coralline formations and aggregations of sea-shells; some of which I have broken from strata of lime rock in the hills around Cincinnati, at an elevation above the level of the tops of the spires of the adjacent city; whilst in the rocks on which the cities of Louisville, St. Louis, and Galena are built, I have found similar organic formations of sea-shells.

Beneath the surface of the soil of the State of New-York, have been discovered, as is stated in recent Geological Surveys, no less than 1800 species of fossil shells and corals.

So extensive, indeed, are these universally extended organic formations of various species of coral rocks, that they have principally contributed to the two grand classifications of all terrestrial matter into "organic" and "inorganic" formations, although produced by the modifying agency of the apparently insignificant organs of a worm of the ocean.

As about one half of the weight of all these coral formations is composed of carbonic acid gas, and as the process of the formation of fresh coralline reefs and islands is continuously going on, the extraordinary consolidation of this gas may be considered as designed, in the economy of nature, to compensate for the continuous production of carbonic acid gas by the artificial combustion of mineral coal by human beings, in addition to the production of it by the decomposition of limestone rocks of the continents of the earth.

Ocean currents of cold water, super-charged with carbonic acid gas, are discoverable, flowing regularly beneath the superstratum of warmer surface water, from all the polar seas toward the equator, where the carbonic acid gas is set free gradually, as the temperature of the sea water becomes increased by the more ardent electro-dynamic action of a vertical sun. The class of Zoöphytes, and of various kinds of shell-fish, are endowed with organs adapted to uniting the atoms of carbonic acid gas, escaping from the gradually warmed sea water, with the atoms of lime abundantly dissolved therein.

Thus is reduced to the static conditions of organic formations of solid limestone rocks, and of vast masses of conglomerated sea shells, a considerable portion of the crust of our planet by means of the propagation of electro-dynamic action through the mechanisms of the organs of a species of shell-fish. Nor is the variety of the shapes of these animal organic formations less wonderful than the extent of them.

Certain kinds of coralline animals organize the groupings of atoms into the beautiful forms resembling the blossoms and shrubbery of a marine flower-garden, all petrified in living stone.

In the Journal of Science and Art, an interesting sketch of the wonderfully diversified forms of this class of marine animals is given by Mr. Dana. In the symmetry of the coral Zoöphytes, he observes, there "are flowers of all hues and sizes. The actiniæ may well be called the asters, carnations, and anemonies of the sub-marine garden; the tubipores form literally its pink beds, the gorgoniæ are its flowering twigs; the madrepores its plants and shrubbery; and astræas often form domes amid the grove, a dozen feet or more in diameter, embellished with green or purple blossoms, which stud the surface like gems; while other surfaces of meandrinæ appear as if enveloped in a network of flowering vines. It is impossible, in any figures or sketches, to convey an idea of the combined effect, where the various species are growing together."

The species of coralline formations, which are usually exhibited as specimens brought from the East and West Indies, consist of the sea-fan, madrepore trees and shrubs, brain coral, &c., but there are very numerous other formations of these classes, some growing in the exact form of large leaves lapped around one another like an open cabbage; and Mr. Dana observes, "cabbage coral" would be no unfit designation for such species. The delicate texture of the crisped leaves of lettuce, of the acanthus and oak, are imitated in stone by others; and even the asparagus bed, mushroom, and other fungi, with mosses and lichens in abundance, add to the variety of fantastic shapes. Whilst even the symmetry of the chastely-formed works of art, as of vases, tiny goblets, and cylindrical cups, are common about the reefs of the Pacific Ocean.

It is sufficient to repay one for a journey to the Capitol of the

United States, merely to see the beautiful and interesting organic formations of coral and shells, deposited in the National Museum, constituting the collections brought from the isles of the Pacific, by the officers of the late Exploring Expedition.

Next in quantity of Organic Formations, constituting considerable portions of the crust of our earth, are the vast strata of mineral COAL, buried beneath the soil in various regions of the earth.

These deposits of groupings of atoms into the constrained static conditions of *fuel*, by the propagation of the electro-dynamic action of antediluvian sunshine on the organs of antediluvian plants, appear to have been systematically produced, and securely hoarded up in accessible localities, for subserving the most important ulterior designs. The control of these sources of natural motive power by finite intelligent beings, must have been originally purposed by the Creator, who has ordained their formation and preservation.

ESTIMATE OF THE QUANTITY OF VEGETABLE ORGANIC FORMATIONS OF MINERAL COAL, CONSTITUTING FUEL, STORED AWAY BENEATH THE SOIL OF DIFFERENT COUNTRIES OF THE EARTH.

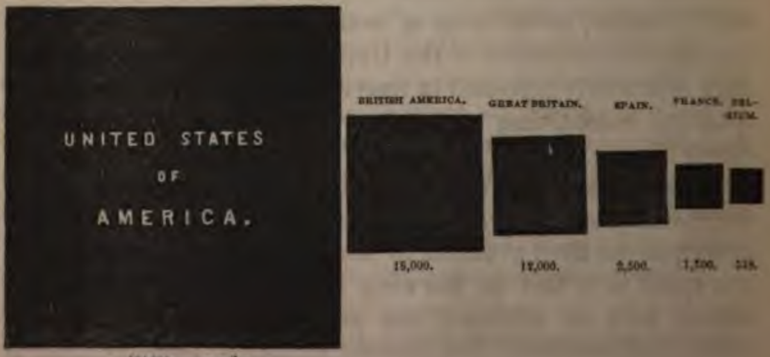
A sort of geological inventory has recently been taken of the stock on hand of mineral coal, stored up beneath the soil of various nations of our earth. It appears by the approximative estimates that have been made, that nearly twelve-fold the quantity of carbon, in the form of available mineral coal, is buried beneath the coal-fields of the United States of North America, than is similarly deposited in reserve in Great Britain; a greater quantity, indeed, than is contained in all the coal-fields of combined Europe.

The possession of fuel carries with it, in the present state of improvements of mechanical science, the possession of physical power, as rendered available in moving armies on the land with the speed of a bird on the wing, and navies on the rivers and oceans, with an efficiency that surmounts opposing currents, waves, and tempests. Our present inquiry is therefore fraught with interesting, as well as instructive information, connected with the future destinies of the intelligent beings, who may inhabit the different portions of the surface of this earth.

In every attempt to form an estimate of the extent of the carboniferous strata of the earth, it is manifest that great uncertainty must prevail. From the very fact that veins of coal are securely covered up, often at great depths, beneath the earth's surface, as if designedly to preserve them from a wasteful combustion, these calculations must partake rather of the nature of approximative suppositions, than of reliable estimates. Sufficient facts, however, of the localities and extent of certain coal-fields have been discovered, to impart to these estimates a considerable degree of probability.

The extent of the deposits of mineral coal beneath the soil of some of the principal countries of Europe has recently been estimated by Mr. Mitchell, as exhibited in the following diagrams. Mr. R. C. Taylor has recently published a similar estimate of the coal-fields of North America. The comparative areas of the coal-fields of Europe and of America are shown by the comparative areas of the following series of parallelograms, as well as by the figures denoting the actual areas in square miles of surface.

COMPARATIVE AREAS OF THE COAL-FIELDS OF VARIOUS COUNTRIES OF EUROPE AND OF THE UNITED STATES.



134,000 square miles.

The deposited vegetable organic formations of solidified atoms of carbon and hydrogen are found arranged in layers or veins, which appear to have once constituted the surface of a compact tissue of fibrous stems, roots, and other woody fibres, such probably as are still found in the level surfaces of peat-bogs. Even massive trunks of trees, with the porous arrangement of their circular rings and bark distinctly observable, are found partially converted into glistening mineral coal.

How this process of reducing vegetable ligneous fibres into mineral coal has been accomplished, and how the coal has become buried up, in some places where it has been found, to a depth of more than a quarter of a mile beneath the present surface of the earth, it is the province of geology, not of mechanics, to attempt to disclose. The facts of the dislocation of the strata of the earth by violent upheavings and sinkings of parts of its crust, with the manifest marks of the action of fire and water on masses of rocks, and on freely movable sands, now constituting successive strata strewn one above another over coal formations, demonstrate most conclusively, that these formations have been buried during very long periods of time. These mechanical effects were probably produced by powerful convulsions of the earth's surface, such as are still found to occur. Very long periods of time, also, must have elapsed for the annual accessions of fresh vegetable organic formations to become accumulated, in many instances to the thickness of twenty, thirty, and even sixty feet. Above some of these deposits of vegetable organic formations are deposited strata of inorganic, crystalline rocks, and even water-worn pebbles, and organic formations of sea-shells, conglomerated into masses.

These investigations present most interesting subjects of physical researches to the geologist, who cleaves the successive strata of rocks, as the scholar opens the successive leaves of a book, to read the history of the past events of the existence of the solid lifeless materials of the crust of this planet, and to gain a knowledge of the existence even of its living inhabitants, whose remains are found imbedded therein.

It is our immediate object more particularly to illustrate the fact, that by the continuous reduction of carbonic acid gas and water to the constrained solidified condition of mineral coal, by means of the solar excitation of the organs of antediluvian plants, the coal deposits now found in the earth represent so many immense reservoirs of temporarily counterbalanced organic and inorganic forces held in static equilibrium, and resolvable at the pleasure of the scientific man into dynamic impulses of inorganic reactions, in the variously modified forms of Heat, Light, Electricity, and Steam Power.

Let the eye of the reader dwell for a moment on the preceding diagrams. They represent the comparative extent of the command of physical power placed at the control of some of the principal nations of this earth. Their comparative pre-eminence in arts and arms is hereafter destined to be decided by the available possession of ready facilities for employing the greatest extent of motive power. In the history of the world it has once occurred, that the possession of the means of rendering effectively available the physical power developed by the combustion of organic carbon and nitre by the invention of gunpowder, carried with it a complete revolution in the art of war, and in the balance of the relative power possessed by neighboring nations. In like manner, the possession of the means of rendering effectively available the combustion of organic carbon by means of the invention of the steam-engine, as applicable to transporting armies on the land and on the ocean, as well as to the purposes of manufacture, is now accomplishing a still greater revolution in both the arts of war and of peace.

The possession of coal and iron by races of men having the knowledge and vigor requisite to use them effectively, constitutes, at the present day, National Power.

The facilities for bringing to the surface of the earth the stores of mineral coal, buried beneath the soil of the United States of North America, is even more remarkable than the extraordinary abundance of it. In most of the coal-fields of the United States, the coal strata are arranged in layers above the level of adjacent valleys; so that the coal may be brought out by level, or descending railways. The labor of hoisting the fuel from great depths, and of pumping water to drain mines, is thus saved. Indeed, the shining masses of coal are to be seen out-cropping where the roads cross numerous hill-sides. Bordering the Atlantic seaboard of the United States, the veins of coal are dislocated by convulsive upheavings and depressions of the earth; but in the valley of the Mississippi, the same thick veins of coal are traceable more than a hundred miles continuously, and nearly horizontally. I have entered a coal-mine on the banks of the Ohio river, from which, in the first rude commencement of mining operations, no other means were employed than a horse and sledge, by which tubs of coal were drawn from an impending coal-bluff, a few yards distant from the boats destined to receive it.

Near Pittsburgh the coal is delivered at the rate of three or four cents per bushel. Nearly an equal facility of access to coal veins in the hill-sides is found throughout a great extent of coal-fields in the great valley of the Mississippi. On the impending cliffs overhanging the Kenawha, one of the tributary streams of the Ohio river, a coal seam is in plain sight of the traveller for many miles, forming a horizontal streak, like a black frontal fillet stretched along the brows of the precipices. Large steamboats have access to the banks of the river in front of these cliffs, from which the coal is caused to descend in railway cars by gravity, and to discharge their burthens into them.

From the base of some of these coal cliffs gush forth springs of salt water; and this ready supply of fuel is here most extensively applied to the purpose of the manufacture of table salt, for the supply of the inhabitants of the great valley of the Mississippi, at a prime cost of about ten cents per bushel.

Even this extraordinary facility for procuring organic carbon for combustion as fuel, has been superseded, within a few years past, by recourse to the spontaneous escape from the depths of the earth of the same kinds of constrained groupings of elementary atoms of carbon and hydrogen, in the form of *carburetted hydrogen gas.* The extent and facility of the employment of this natural coal gas, which is here rendered available for the boiling of brine in the production of salt, constitutes one of the most remarkable phenomena of the spontaneous production of *liquid fuel* which our planet affords. Another similar instance occurs in China.

The gratification here derivable from viewing the profuse displays of the bountiful provision of two important necessaries of life, for the supply of the wants of the population that is destined to occupy the fertile valley of the Mississippi, amply rewards the toil of the exploring geologist. The following details are given as the results of personal observations made in the year 1847, at the "*salt* springs" and "*gas* springs" on the banks of the Kenawha river, where it intersects the mountains of western Virginia.

It had frequently been noticed by the early settlers of this wild region of mountainous country, that bubbles of air were constantly rising to the surface of stagnant pools of water. On applying a lighted candle to test the nature of the escaping bubbles, they discovered that the pools became covered with lambent flames, producing the phenomenon familiarly called "burning springs." These springs were regarded as objects of curiosity by the inhabitants of the vicinity, as similar springs usually have been, when discovered elsewhere.

A few years ago, the proprietor of one of the salt-works on the banks of the Kenawha river continued to bore, or drill, into the rocky substrata of the earth, to the depth of about 1,000 feet, for the purpose of obtaining stronger brine springs. Whilst continuing the operation of drilling, the steel chisel finally broke through a stratum of rock into a crevice beneath it. Instantaneously a powerful torrent of commingled air and brine gushed upwards with great violence, jetting into the air like the stream discharged from the pipe of a fire-engine.

Astonished by the appearance of so much air commingled with the uprushing brine, one of the workmen applied a lighted candle near the orifice to ascertain if the air were inflammable. It flashed up into a lofty jet of flame, like that of an immense gas-burner, presenting to view the extraordinary spectacle of a jet d'eau of sparkling spray, commingled with wreaths of dazzling flames.

The timber framework erected for working the drills, and all the combustible portions of the apparatus, were speedily burnt up. Every attempt to extinguish the flame having proved unsuccessful, the proprietor had begun to despond, instead of rejoicing at the result of his labors. At the suggestion of one of the workmen, the end of a pipe was placed in an erect position over the orifice of the drill-hole, and then dexterously removed, whereby the continuity of the streams of gas was broken, and the flame was thus readily extinguished.

On approaching one of these Artesian wells, or rather spouting fountains, which had just been successfully drilled to tap the subterranean magazine of fluid fuel, we were at first startled by the unearthly sounds produced by the violent belching forth of the brine and gas. The intermitting noises, resembling the hoarse, asthmatic pantings of a powerful locomotive engine, were audible at the distance of a mile. At the same distance the intermitting jet of water appeared spouting upwards to the height of about forty feet, involving in clouds of spray the lofty framework of timbers, erected for lifting and dropping the long drill-rods with a churning motion.

Near this recently completed Artesian well were located extensive ranges of sheds of "salt works" in full operation. Here we were informed that 2,400 bushels of salt are obtained weekly from the brine, which is spontaneously discharged into a huge boiler, and is there evaporated by the combustion of the carburetted hydrogen gas spontaneously discharged through a tube into the furnace beneath it.

In order to take a systematic survey of the works, our guide first conducted us by the descent of the river bank to the edge of the Kenawha. Here the top of the copper tube of the Artesian well, of the diameter of about three inches, appeared projecting above the surface of the rocky shore. Connected with the top of the tube was a range of wooden pipes, or bored logs, laid in an ascending direction upon the precipitous river bank to the level of an alluvial plain, on which the works are located.

The uprushing currents of commingled brine and gas caused the bored logs to tremble, and to emit rumbling sounds. Following the direction of these conduit pipes, we came to a large cistern made of planks, and elevated on posts, about forty feet above the level of the top of the tube of the Artesian well.

The separation of the commingled brine and gas is readily effected in a very simple manner. A rude gas-holder, constructed of the hollow trunk of a sycamore—one of the ancient monarchs of the forests of the west, and still covered with its bark and moss—was arranged like an inverted tumbler over a basin of water. The gas being specifically lighter than the water, rises into the chamber formed by the hollow trunk of the tree, arranged over the orifice of discharge of the wooden pipe through the bottom of the cistern, whilst the brine subsides to the bottom of the reservoir. By means of this cheap and primitive apparatus, the separation is speedily accomplished, accompanied with violent spasmodic tremors caused by the intermitted forcible influx of the currents.

Descending by a ladder from the top of this cistern of brine and reservoir of gas, we were conducted by a guide in the direction of two other wooden pipes; the one terminating over a shallow iron boiler, a hundred feet long, raised on two parallel walls of brickwork, and the other terminating in a furnace of equal length, and of the width of about five feet. The furnace resembled a hall with an iron ceiling.

To supply fluid brine to this huge salt-pan, and fluid fuel to the huge furnace beneath it, no other labor was requisite than that of opening faucets.

The superintendent of the works withdrew a loose brick from the front wall of the furnace to allow us to view the scene of combustion taking place within it. Involuntary exclamations of wonder and astonishment burst forth from the lips of each one of our party, successively, on obtaining a first sight of the grand spectacle of the conflagration of the gas. Billows of fire appeared waving and tossing beneath the iron canopy, extended horizontally to a distance of a hundred feet.

This sublime scene of continuous billows of flame may be imagined, by supposing a large burner, connected with the gas-works of a city, to emit a blaze towering to the height of a hundred feet, and spread out like a fan, flashing and curling in wreaths of resplendent brilliancy.

Turning from this dazzling and bewildering spectacle, and following a branch of the wooden gas-pipe, we were next conducted to another furnace, into which a stream of gas was discharged, and burnt beneath the boiler of a steam-engine. The engine was in vigorous action, to operate the drilling apparatus used for boring still another Artesian well.

This additional view of the development of motive power by the mechanism of a steam-engine operated with fluid fuel, spontaneously gushing forth from the earth like water from a fountain, serves to overwhelm the spectator with surprise.*

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* A fellow-traveller, on contemplating this exciting scene, ascribed the discharge of the combustible gas to "the geological fact of the thinness of the crust

The furnace fires are kept glowing incessantly by night and by day, requiring no other attendance than what is necessary to draw off the crystallizing brine into other shallower evaporating pans, through which the steam from the great iron boiler is conducted in copper pipes. The subsiding crystals of salt are occasionally raked out, and are packed in barrels for transportation throughout the valley of the Mississippi. The quantity of gas discharged from one of these "gas wells," has been estimated by a writer, in Silliman's Journal, to be sufficient to fill a reservoir large enough "to light the city of New-York during twelve hours." This extreme estimate is probably much too high.

The only rational mode of forming an approximative estimate of the actual quantity of carburetted hydrogen issuing from one of these gas springs, appears to be founded on the quantity of water evaporated in the process of boiling down the brine.

Taking the daily product of salt to be 400 bushels, and the evaporation of about 75 gallons wine measure being required to produce one bushel, 30,000 gallons of brine per day must be evaporated. As the steam arising from the great boiling pan was not suffered to pass off directly into the atmosphere, but was conducted through copper tubes immersed in adjacent brine cisterns, to render available the heat set free during its condensation, it may be estimated that with this advantage the combustion of gas equivalent, as fuel, to 1 lb. of coal, might suffice to evaporate 1 gallon of brine. The combustion of 30,000 lbs., or 15 tons of coal per day, would thus be requisite to evaporate all the brine which is converted into vapor by the combustion of the stream of gas here issuing from a drill-hole in a rock.

To estimate the extent of motive power, which might be rendered available by means of the combustion of this gas for operating a steam engine, it may be calculated that 100 lbs. of coal per day are adequate to developing impulses of mechanical force equivalent to *one* "horse-power." By this estimate, it appears that an extent of motive power equal to that of about 300 horses working 12 hours per day, might here be brought into action by simply turning a faucet, being less manual labor than that of

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of the earth at this place, and to a consequent tapping of the infernal regions by the augur-hole."

opening the gate in the sluice-way of a water-wheel. To obtain this result of efficient motive power, proceeding from a small drill-hole in a rock, nearly half a dozen water-wheels and the waterfall of a great river would be required.

The superintendent of the drilling operations, in progress at one of the salt-works, stated that a proprietor had persevered in boring at another spot to the depth of 1850 feet, in an unsuccessful attempt to obtain a supply of gaseous fuel for boiling brine. This extraordinary artesian well is therefore of about the same depth as the celebrated artesian well of Grenelle, in the city of Paris. The temperature of the brine is not tepid, like the warm water gushing forth from the artesian well in Paris. The solution of the solid crystals of salt probably produces the reduction of temperature.

The quality of this natural gas is of the most refined purity, being entirely devoid of the nauseous odor, which characterizes the carburetted hydrogen artificially produced in the gas-works in our cities.

When we reflect that this same kind of gas has been constantly issuing from the depths of the earth in this vicinity, as palpably discoverable in stagnant pools by the rising and bursting of the bubbles on the surface of the waters of 'burning springs,' we become lost in astonishment at the vastness of the extent of the elaboration of this product of vegetable organic formations, which is going on in the depths of the earth. From the bituminous coal originally organized by the agency of plants, and buried up in some unaccountable manner in the depths of the earth, this source of natural motive power is thus rendered available by man, by a process of natural coking, the residuary anthracite or flameless coal being the result.

This region of country appears to be a frontier between the bituminous coal-fields of the valley of the Mississippi, and the anthracite coal-fields of the Atlantic States.

That there is a powerful electro-dynamic action going on in the depths of the earth in this region, is manifest from the fact of the HOT SPRINGS that gush forth unceasingly in the valleys between the adjacent mountains.

From recent information received from this interesting region of country, I have learned that beds of solid rock-salt have been discovered, and veins of cannel coal.

It becomes an interesting question, which remains to be solved by the test of time, how long will the supply of this fluid fuel continue to gush forth?

The first artesian gas spring, after pouring forth a continuous stream of gas during a period of three or four years, has become gradually exhausted; but four or five other similar artesian wells have been successfully made within two or three miles of the original one.

A recent communication from Mr. S. A. Lewis, addressed to me in reply to a letter of inquiry, contains the latest intelligence on this subject. He states that the gas has not failed entirely, but is liable to be suddenly cut off from one well, and to be diverted in a few minutes to another at a distance, perhaps on the opposite side of the river. The supply still continues adequate for two salt-works, one of which has produced four hundred bushels of salt per day.

From the preceding facts, it appears that this great quantity of gaseous fuel has been unceasingly elaborated and discharged from the depths of the earth during a period of eight years, and that the supply still continues sufficient for two of the furnaces above described.

Whilst surveying these regions, abounding in stores of the organic formation of solid and gaseous fuel, and of inorganic crystalline formations of table salt, treasured up for the use of the future generations of men destined to occupy the great valley of the Mississippi, the traveller cannot refrain from indulging in a train of musing on the important influence which these resources must have in developing the prosperity and happiness of the inhabitants of the broadest fertile region on the surface of this planet.

THE POSSESSION OF ORGANIC FORMATIONS OF CARBON, OR MINERAL COAL, CONSIDERED AS A SOURCE OF NATIONAL POWER.

The preceding statements of the quantities of mineral coal available by some of the most important nations of the earth, demonstrate that the Anglo-Saxon race, who have taken possession of the continent of North America, possess the control of a greater extent of coal-fields than all Europe combined. The physical power, commanded by this fuel for steam navigation, and for the useful arts, is at the present epoch just beginning to be developed by the vigor and enterprise of its possessors. When the present wildernesses of North America shall have been made "to blossom as the rose," this physical power will be felt, for weal or woe, by all the nations of the earth.

In taking this practical view of the sublime extent of physical force, which is manifestly to be hereafter exercised by the inhabitants of the New World, we may realize the glowing anticipations of the future greatness of America, which Berkeley depicted in his prophetic verse:—

"Westward the course of empire takes its way,
The four first acts already past,
A fifth shall close the drama with the day;
Time's noblest offspring is the last."

As the mode of employing a paramount physical power in controlling the affairs of men is a more important consideration to the interests of humanity, than the possession of it as a mere brute force, it certainly will not here be considered inappropriate to illustrate this interesting question of the most beneficially effective employment of Natural Motive Power.

The possession and control of the means of developing the greatest extent of physical power does not necessarily carry with it "the course of empire;" for brute force applied to subjugating the wills of men to tyrannical sway, although it may for a time prevail, must eventually yield to the paramount moral power, which finally determines the volitions alike of the soldier and the savage. A sense of the "rights of life, liberty, and of the pursuit of happiness," is recognized by each individual soldier, who serves as the tool of despotic violence, and finally prevails in arresting his course as an executioner. The history of man, in all ages of the world, is fraught with instances where the same hands which have been obediently lifted to smite and oppress, have been in turn revoltingly uplifted to smite down the oppressor.

This reaction serves to illustrate the establishment of a compensating principle between moral and physical laws, and to show that the former control the latter, so as finally to promote the greatest good of the greatest number.

It is only when physical power is directed beneficently that its sway becomes irresistible. For when each individual of a nation yields to the moral power of beneficence, the human muscles are arrested in their resisting energy by the will. There can be no human resistance, where the wills and energies of men accord. The "course of empire," under such circumstances, might bring all nations under one common sway of the most efficient, beneficent controlling power.

By employing this vast extent of physical power in accordance with beneficent moral power, by diffusing the blessings of free institutions, and by augmenting the sum of human comforts and happiness, the Anglo-Saxon race may go on "conquering and to conquer," by the arts of peace, rather than by those of war, rendering "annexation" another name for the practical acknowledgment of subjection to the combined power of the physical and moral laws, which God has manifestly ordained to govern his universe.

The early Roman conquests were similarly extended over the world by conferring the benefits and privileges of Roman citizenship on distant nations, who bowed before the progress of the Roman eagles. When the same emblems of liberty were first carried abroad by republican France, they were hailed by the mass of the people of the invaded countries as representatives of beneficent power,—as harbingers of release from despotism. The republican eagles might have been welcomed by the Russian serf, who repelled the imperial eagles of France. The myriads of people of British India were subdued rather by the moral power of Anglo-Saxon justice and respect for the rights of man, than by the few soldiers, who employed a shadow of physical power to achieve the conquest of nations.

The great and thrice glorious example has been recently held out to the world by the English nation, of the employment of the physical, national power, heretofore devoted to the arts of war, in the promotion of the arts of peace. Fleets, which in former ages were employed solely for hostile collisions between people separated by intervening seas, are now furnished with steam power to speed them as swift-winged messengers for the beneficent purpose of facilitating friendly intercourse between the inhabitants of distant shores. Every individual, who is hospitably received on board one of these national steamships, and is safely transported therein against adverse waves and tempests, cannot but realize a kindly feeling, even toward the very ship, which for a time has been his home, as well as for the flag under which he has found a beneficent reception.

In the early settlement of New England, it was proposed, in the British colony of Massachusetts, by Roger Williams, the founder of the present State of Rhode Island, to efface the cross from the British standard, as being a Christian emblem unworthily sustained in the union of Church and State. It may yet remain for the descendants of the early settlers of New England to acknowledge this emblem of the cross to be worthily unfurled in the English banner, in practically extending peace and good-will to men of different nations, by facilitating their friendly intercourse and rivalry in the arts of peace.

The present harmonious assemblage of the inhabitants of various nations of the earth at the "World's Fair" in England, may be deemed the harbinger of a future system of friendly intercourse of men of every clime. The honorable appreciation of the science, taste, and industry, devoted to the arts of peace, by the sovereign whose private merits eclipse the glory of her exalted public station, has excited a thrill of kindly emotions, that now pervades the world. It has awakened a common sympathy between the greater portion of mankind, whose dependence is on the labors of the head and of the hand; and has tended to elevate democracy to the standard of philanthropy. It has also brightened the cheering hope, that the time may be fast approaching, " when nation shall not lift up sword against nation, neither shall learn war any more."

The frequency of intercourse between the inhabitants of opposite ocean shores, afforded by the active employment of vessels of war as steam-packets, instead of allowing them to float idly in port, or to carry defiance abroad with their tiers of bristling cannons, has led to a more intimate and kindly intercourse between the individuals of rival and once hostile nations. The use of the organic formations of mineral coal as fuel for promoting this benign purpose of facilitating friendly intercourse among the inhabitants of the earth, appears to be in fulfilment of the original design of extending good-will among men, for which the antediluvian sunshine was caused to quicken the unoccupied surface of this planet. It practically dispels the barbarous idea, that the inhabitants of different portions of the same orb of matter are "natural enemies" to each other, by associating foemen together hospitably under their associated flags. The French and the English banners may now be seen floating together harmoniously in the same breeze from the masts of the war steamers of both of these powerful nations. At the station of the British North American steam-packets in the harbor of New-York, the red cross and the stars may be seen even quartered together in the same field of blue:—a delightful emblem of the reunion of the interests of the parent and the offspring.

This spirit has also become extended to the decorations of the new class of fast-sailing vessels of the mercantile marine, such as were once only modelled for barbarous plunder, as privateers. Ornamental groupings of different national colors may be seen affixed thereto, indicative that the acts of peace bind together the interests of all mankind, as if they constituted one common family.

The employment of an American ship of war in transporting food for the famishing population of one of the British isles on a mission of beneficence, softened more brave hearts in the sister isle of England, than ever were subdued in any victory of the most powerful fleet that has triumphed on the ocean waves, as when the fleet of Van Tromp exultingly sailed through the British channel with a broom affixed to the mast-head, in token of sweeping the seas of vanquished foes.

The influence which this blending of national emblems and of national sympathies is destined to have in the future history of the world, remains yet to be developed. In watching the progress of the extraordinary events resulting from the common use of organic formation of food and fuel by the human family, the man must be endued with a stern nature, who feels no glow of kindly sympathy awakened in his cold bosom; or who can continue to regard with indifference the progress now making to unite nations situated under various climes, by reciprocally administering to each other's physical wants, the supplies of organic formations of food, fuel, and materials for clothing, produced by the variously modified electro-dynamic action of the sun on the different parts of the surface of one common orb of terrestrial matter.

Should the Anglo-Saxon race of the New World employ the vast extent of physical power placed at their control in the beneficent arts of peace, and in carrying out the true design of free institutions, the enthusiastic prediction of Berkeley may become verified; and the future history of the world may truly show that—

> "Time's noblest offspring is the last."

ON THE DURATION OF THE SUPPLY OF ORGANIC FORMATIONS OF CARBON IN THE FORM OF MINERAL FUEL, AVAILABLE FOR SUSTAINING MOTIVE POWER ON THIS PLANET.

Science teaches us, that in finite space infinite progression cannot take place. It might hence be naturally supposed, that the limited stock of carbon already organized into mineral coal, by the agency of plants, and stored up beneath the surface of our earth, may finally become exhausted by the continually progressive and increasing draughts upon it. The consumption of coal in the useful arts, and for purposes of navigation, is destined to go on annually increasing to a vast extent; and no new deposits of coal are now forming availably for replenishing this waning supply.

However great may be the present stock of mineral coal in the strata of the earth, it is to be remembered that the science of geology teaches us that a lapse of time, which in human affairs might be deemed infinite, was occupied in the collection and organization of these masses of atoms of carbon by the protracted action of the solar excitation on the organs of plants. With the rapid increase of population on the surface of our earth, and the far more rapid ratio of increase of the combustion of coal, it may be calculated that at the termination of one of these geological cycles of an almost infinite series of years, the last coal-fields may become exhausted, and the shivering inhabitants of these same coal-fields, may be compelled to have recourse to gathering a few sticks of fuel from their over-populated surface, as the poor widow gathered them to cook her last meal. The lively steam engines, deprived of the exciting cause of their powers of action, may then cease to give forth the puffs of their vapory breath, and remain motionless as famished animals; and even the sounds of the cheering simmer of the tea-kettle might expire.

Improvements in the science of agriculture may enable future generations of men to accomplish the task of causing plants on the surface of our planet annually to produce greater quantities of organic carbon, for replenishing exhausted granaries; but we can conceive of no resource of art that can be made available for reproducing the organic formations of carbon as a substitute for exhausted coal-mines.

By the diminution of the available motive power of mineral coal, a corresponding diminution would also ensue of all the productions of clothing, and of other appliances of manufactures necessary for sustaining the excitation of the vital powers of human beings, and the existence of a dense population. The comparative extent of the habitable condition of the earth, and the diminution of the number of its inhabitants, with a retrograde in the arts of civilization, appear therefore to be contingent on the combustion of the portion of its surface composed of ORGANIC FORMATIONS of strata of coal.

History teaches us that progress in improvement is a law of the moral and physical condition of man. This might not be anticipated, if the present coal-fields may fail of yielding a supply of organic carbon as fuel necessary to supply the wants of a teeming population; as the forests have already done in some of the principal countries of Europe. A compensating principle, it has been imagined, may be discovered in artificial modes of producing atomic groupings of carbon, as has apparently been effected by the recent invention of gun-cotton, of electro-magnetic engines, and of modes of decomposing water into hydrogen gas as fuel, so as to procrastinate indefinitely the final exhaustion of the stores of mineral coal in the earth.

It would be rash to pronounce that such compensatory discoveries never will be made; but, in accordance with the principles developed, there must necessarily be a reduction of atoms to constrained static conditions of food and fuel by the electro-dynamic action of the sun, before there can be propagated a reaction on recoiling to their natural static conditions. There appears to be left no rational ground for anticipating that any such discoveries of newly-modified groupings of atoms will ever be made to take the place of this waning supply of the organic formation of fuel produced by antediluvian sunshine.

After the lapse of one of those periods of myriads of years constituting a geological cycle, bordering on infinity in the estimation of finite intelligences, the progress of mankind may be advanced to the full measure of its destined career on this orb of matter. There may then occur again one of those geological pauses, which the appearances of the present crust of the earth demonstrate to have repeatedly taken place. There is no other imaginable design assignable for the existence of our planet, in a state of gradual renovation, during the long dawn which geologists have denoted by the term "EOCINE PERIOD," than that of a pause adequate for the electro-dynamic action of the sun to reorganize terrestrial matter, in preparation for the future use of renewed races of intelligent beings.

To the revolutions of all the huge orbs of matter in the vast space of the heavens are assigned circles of rotation and of revolution. *Periodicity* is one of the primary laws, on which the science of the stars is based. The successively recurring seasons, the annual springing forth of the bud, of the blossom, of the seed, is the preparation for a renovated germ; and the perpetuation of renewals of animal existences and of finite intelligences appears to be the principal mechanical design manifested by the creation of all the natural mechanisms of vegetable and animal organic formations on the surface of this planet. In harmonious keeping with this progressive cycle to all terrestrial essences, is the idea of a cycle of the final aggregate sum of the intelligence of the human race.

Here must terminate our speculative conjectures in relation to the duration of the exciting causes of motive power available from the combustion of Organic Formations, considered as *food* and *fuel*. The boldest attempts of reason to anticipate the mysterious future, or to account for the equally mysterious past condition of our planet, with its evanescent inhabitants, can adventure no further.

ANIMAL ORGANIC FORMATIONS.

RE-ORGANIZATION OF VEGETABLE FORMATIONS INTO ANIMAL ORGANIC FORMATIONS OR BODIES.

THE four organic elements are the principal constituents of the flesh and blood of animals. The rigid frameworks of both vegetable and animal substances are found to be composed of several other kinds of elementary atoms. The bones are constituted of groupings of atoms of lime and phosphorus; and the presence of silicon and potash are always found in the solid skeleton parts of plants. A little iron is present in the blood, and very minute portions of the following substances complete the list of the materials of all the organic formations in connexion with which life and intelligence are found to exist on the surface of the earth: viz., sulphur, sodium, magnesium, chlorine, iodine, fluorine, and manganese.

The presence of some of these kinds of atoms appears to be incidental rather than essential to the constitution of animal bodies.

Considering plants not to be intelligent, sentient beings, we can only regard them as mechanisms designed to become excited by the electro-dynamic action of the sun, and to modify the propagation of this electro-dynamic action, like real electrical machines, to decompose water and carbonic acid gas. But the systematic regrouping of these decomposed atoms into a perpetual succession of similarly-continued machines, with a presence of the chemical effects producible by the specific mechanical groupings of atoms into the several fluid and solid parts of such machines, transcends all laws of mechanical science, as has been before stated.

The functions of the organs of plants and of animals are exactly the reverse of each other. The leaves and roots of plants, which perform the functions of the lungs of animals, absorb carbonic acid gas, and decompose it, rejecting the atoms of oxygen, and incorporating the atoms of carbon into the vegetable organic formations constituting food to be burnt in the lungs of animals, and fuel to be burnt in furnaces. The functions of the lungs of animals are confined to the absorbing of the atoms of oxygen of the atmosphere, set free by plants, to become reunited with those of the carbon solidified by them into food, to be subsequently converted into blood, and then breathed forth from the lungs in the restored form of carbonic acid gas. Plants organize; animals reorganize and disorganize. The former inspire carbonic acid gas, which is expired by the latter. What is food to the one is poison to the other.

This remarkable fact of the continuous restoration of vital air to the atmosphere, through the agency of the leaves of plants, serves to compensate for the continuous consumption of it by the process of combustion and breathing of animals. Sir Isaac Newton, from an ignorance of this fact, supposed that the functions of the atmospheres of comets might be designed to furnish to the atmospheres of the planets this compensating supply of vital air, to preserve the due balance, which might otherwise have been finally deranged in the workings of the mechanism of nature.

Indeed, the organs of plants are all designed to modify the propagation of the electro-dynamic action of the sun reciprocally between the centres of the atoms of the four organic elements oppositely to the directions in which the organs of animals modify the propagation of the same electro-dynamic action, their functions being precisely antagonistical to each other, as is exhibited in contrast in the following Table.

ANTAGONISTIC FORCES AND FUNCTIONS DEVELOPED BY THE OPPOSITELY MODIFIED PROPAGATION OF THE ELECTRO-DYNAMIC ACTION OF THE SUN, THROUGH THE MECHANISMS OF THE ORGANS OF PLANTS, AND OF THE ORGANS OF ANIMALS.

The electro-dynamic action of the sun, when propagated through the modifying agency of the organs of—

—Plants,		—Animals,	
Reduces groupings of atoms of	Carbon, Hydrogen, Oxygen, Nitrogen,	*Restores* the same atoms of	Carbon, Hydrogen, Oxygen, Nitrogen,
From their natural fluid inorganic static conditions of	Water, Carb. acid gas. Nitrog'n of air,	*To* their natural fluid inorganic static condition of	Water, Carb. acid gas, Nitrogen,
To the constrained solid organic static conditions of	Vegetable organic formations;	*From* their constrained solid organic static conditions of	Vegetable organic formations;
and continuously sustains these groupings of atoms of vegetable formations in the variously modified conditions of		and continuously sustains the groupings of atoms of animal formations in the vaously modified conditions of	
Cohesion, as exhibited in	Hemp, Flax, Cotton, &c.;	Cohesion, as exhibited in	Silk, Wool, &c.;
Elasticity, " "	India-rubber, Wooden-springs, &c.;	Elasticity, " "	Whalebone, Horn, &c.;
Acids, " "	Lemons, Sorrel, &c.;	Acids, " "	Oils, Fat, &c.;
Alkalies. " "	Morphine, Strychnine;	Alkalies, " "	Saliva, Gastric juices;
Food, " "	Cereal grains. fruits, and grasses;	Food, " "	Meats, Fishes;
Fuel, " "	Wood, Peat, &c.:	Fuel, " "	Oils, Fats, &c.:

developing,

during the recoil of all these groupings of atoms of both vegetable and animal organic formations to their natural static condition of carbonic acid gas and water, the inorganic re-action popularly recognized as the phenomena of

FERMENTATION,
COMBUSTION,
HEAT,
LIGHT,
ELECTRICITY,
STEAM-POWER,
ANIMAL MOTIVE POWER.

TRANSFER OF VEGETABLE ORGANIC FORMATIONS, CONSTITUTING FOOD, INTO ANIMAL ORGANIC FORMATIONS.

Common observation teaches us that animals are dependent for their original supply of food on the vegetable organic formations.

There exists on the bare surface of granite rocks, in bleak northern climes, an humble lichen or moss, which the famishing Canadian "voyageur" gladly seeks out as food to sustain his animal motive power, daintily denoting it by the figurative name of "Tripe de roche." The self-styled 'lord of creation,' stoops down to cherish with annual toil the humblest vegetables of the garden, and in the labor of cultivating them he breathes out upon their leaves the very carbonic acid gas which he strives to reclaim and re-organize into food through their agency.

He burns the organic carbon that he reaps in one harvest, to develop the motive power necessarily expended in tilling and reaping a succeeding harvest.

Thus the life-power of the vegetable kingdom serves to provide the supply of food to sustain the life-power of the animal kingdom, as the jackal is fabled to purvey for the lion.

A portion of the grouping of atoms of carbonic acid gas and water into the vegetable organic formations of food, becomes incorporated into the mechanisms of the bodies of animals to increase their strength in the progress of their growth, and to replace the deteriorated portions excreted. But by far the greater portion of all the food eaten by animals is actually burnt in the lungs, as is fuel in a locomotive boiler, to develop locomotive powers.

The portion of the vegetable organic formations, which becomes transferred to the bodies of graminivorous and of frugivorous animals, and incorporated therewith, admits of being reorganized repeatedly by successive classes of carnivorous animals, which devour each other.

Plants having no need of the development of motive power for locomotive purposes, as has been premised, require not the combustion of carbon. On the contrary, they serve as stationary mechanisms, exposed to solar excitation, to collect the fluid atoms of carbonic acid gas and water from the atmosphere surrounding their leaves, and from the water in the earth about their roots. They reduce the component atoms to the constrained static condition of groupings of the vegetable organic formations constituting FOOD and FUEL, the former capable of being reorganized into the mechanisms of animal bodies, or of being burnt in their lungs, the latter being appropriated to undergo the same process of combustion in the artificial mechanisms of steam boilers.

Animals, on the contrary, having no organs adapted to reducing any one of the elements of the air, water, or earth to the form of food, are under the necessity of employing constantly animal motive power to propel their bodies in search of the vegetable organic formations constituting their food. Every species of animals,—not even excepting man, are forced to devote most of their physical and intellectual powers to the collecting of the various kinds of organic formations, constituting their food.

To win their respective supplies of groupings of atoms constituting their several appropriate kinds of food, plants as well as animals appear to exert a constant struggle in competition with each other.

In pursuing these analogies, the most superficial observer cannot fail to be impressed with the resemblance between the struggles of plants for gaining a supply of their appropriate food, whilst crowded together in their dense growth, and those of men in the crowded ranks of social life. Each severally strives to monopolize a greater share of the vivifying action of the sun, and to overshadow its neighbor,—to win possession of a greater extent of broad acres of sunny fields, for obtaining the utmost available means of reducing carbonic acid gas and water to the organic formations of food, to serve as provisionary stores for their own well-being, and for the supply of the anticipated wants of their offspring.

The allegory admits of extension even to the uncertainty of the fruition by the offspring of the accumulated wealth of these hoarded provisionary stores of food, laid up in reserve by the provident care of the parent plant and human parent. Classes of surrounding animals seize upon the food destined for the germ,—the heir to each plant,—and appropriate it to their own use as spoils; whilst the greater portion of mankind "toil for heirs, they know not who."

Particular classes of herbivorous animals seek out appropriate particular classes of vegetable organic formations, as food to become reorganized into the mechanisms of their respective bodies, or to be burnt in their lungs to develop animal motive power. Man, alone, selects from the organic formations of both the vegetable and animal kingdoms, the cereal grains, and the flocks and herds,—the birds of the air and the fishes of the waters.

On every spot where organic formations, constituting food, exist, there animals appear, and "gather up the fragments, that nothing be lost" in the economy of nature. The principle of the general design of the propagation of the quickening electro-dynamic action of the sun in the production of organic formations constituting food, appears to be carried out to an extreme extent for developing the greatest possible number of animal existences, and of animal enjoyments; for even the organic formations of "peerless man" finally serve as food, and become a prey to worms, who convert every charnel-house into a banqueting hall.

After plants and animals have accomplished their destined functions of collecting and organizing the groupings of atoms of the organic elements into vegetable and animal organic formations, they have fulfilled the plan of propagating a succession of similar vital agencies. They continue as self-renewing mechanisms to organize and reorganize the same kinds of elementary atoms over and over again in never-failing succession, in the regular perpetuation of the species. The paramount life power in each individual mechanism, ceases finally to modify the propagation of the electro-dynamic action of the sun. Then the antagonistic, inorganic propagation of the same electro-dynamic reaction prevails, and restores the wonderfully framed mechanisms of all organic formations to their natural static conditions of fluid air and water.

Scientific observations teach us that a very small portion of the food taken into the stomachs of animals becomes permanently assimilated therein to form solid parts of their mechanisms. The weight of a healthy laboring man rarely varies more than a few pounds in a term of several years; whilst the gross weight of the elementary matter, which he takes into his stomach, may considerably exceed a ton each year.

It appears from the result of an experiment made on a large scale with 856 soldiers, by ascertaining the quantity of carbon contained in the food furnished to them as rations, and the quantity of urine and excrements voided by them, that only about $\frac{1}{27}$ part of the carbon was thus unavailably wasted; and that consequently $\frac{26}{27}$ parts of the carbon consumed as food was burnt in the lungs, and converted into the carbonic acid gas discharged therefrom in breathing.

The phenomenon of Heat becomes also as certainly developed by the combustion of food in the animal body, as by that of fuel in a furnace; and hence "animal heat," which was once deemed one of the most wonderful of all the mysteries of life, has been accounted for, in accordance with established laws of chemical science.

From the accounts which have just been given of the successive vibrations of the organic elements of carbonic acid gas and water, from their natural static conditions of inorganic formations, to vegetable organic formations, and of their re-organizations as food into animal organic formations, with the transitory duration of vegetable and animal life, from the threescore and ten years of human age to that of 'the insect of an hour,' it is manifest that the same atoms of carbon, hydrogen, oxygen, and nitrogen, must have been moulded and re-moulded many times over into vegetable and animal organic bodies.

By the test of numerous experiments, it has been ascertained that a vigorous man breathes forth from his lungs a volume of carbonic acid gas, which, by analysis, is found to be composed of about 13 ounces of pure carbon. This quantity is equivalent to about the same weight of pure charcoal; which is burnt and reduced to gas, to propagate the electro-dynamic excitation constituting animal heat and animal motive power. At this rate a man burns in his lungs about twice his weight of carbon every year. A man, therefore, consumes in the allotted period of the threescore and ten years of his life a stock of about ten tons of carbon, or charcoal, to develope animal heat and animal motive power.

This quantity is supplied by the fluid blood, which, when dried, consists of nearly one-half part of carbon. This fact may be readily tested by exposing dried blood in a covered crucible to a red heat. The residuary charcoal left in the crucible cannot be distinguished from the charcoal left in the same crucible, after bread, sugar, wood, flesh, and other organic vegetable and animal formatives of food and fuel, are subjected to a similar treatment.

These constant organizations and disorganizations of vegetable and animal organic formations having been incessantly produced by the electro-dynamic action of the sun upon the surface of this planet, from the antediluvian period of its geological history to the present moment. The invisible carbonic acid gas floating in the atmosphere around us may have repeatedly served to swell the throbbing tides of life in successive species of animals and plants. Some of the atoms now constituting the blood circulating in our veins may have once circulated in the veins of an antediluvian mammoth, or may have been burnt in the mechanisms of animal lungs to quicken the flight of a turtle dove, the agility of a monkey, or the writhing contortions of a boa constrictor.

These allusions to the successive transmutations of the groupings of the same atoms into various animal bodies, are not to be deemed derogatory to the real dignity of man; for it is not the mechanical groupings of atoms into blood and sinews, which elevate human beings above the brute creation. It is rather the exercise of a spirit of intelligence, directed by christian principles, which ennobles the character of man, by animating the mechanism of the human body to the performance of acts of beneficence. It is thus truly consecrated to the sublime dignity of serving as a living temple devoted to the worship of its Creator.

PROBABLE NUMBER OF SPECIES OF ANIMAL ORGANIC FORMATIONS OCCUPYING SPACE ON THE SURFACE OF THE EARTH.

Human organic formations are included in only one species,—mankind.

The number of species of birds are estimated (Principles of Zoölogy, by Agassiz and Gould) at about 6000; of reptiles, at 1500 described species, and they will probably reach 2000; of the fishes, there are about 5000 or 6000 species in the museums of Europe, and the number may probably amount to 8000 or 10,000. The molluscs enumerated in collections, probably reach the same number. The various species of univalve and bivalve marine shells exceed 5000, and of land and fluviatile shells 2000, making the total number of species of molluscs more than 15,000. Of the articulated animals, it is difficult to estimate the number of species. There are probably 60,000 or 80,000 species of insects; and in the department of articulata, comprising crustacea, the cirrhipeda, insects, the red-blooded worms, intestinal worms, and the infusoria, as far as they belong to this department, the ascertained number already amounts to 100,000.

If to this be added about 10,000 for radiata, echini, starfish, medusæ, and polypi, there exist on this planet about 250,000 species of living animals, endowed with different grades of intelligence and locomotive powers.

The number of individuals constituting these several species, to our finite comprehension, appears to approach infinity. Even the cold waters of the Polar regions teem with living animalculæ, and in warmer climes each leaf of forest trees sustains living beings. That no space may be lost, one species is even found living within and upon the bodies of others.

It has been calculated that the number of animal mouths associated beneath the domiciliary architecture of the conjoined shells of a *porites* of about twelve feet diameter, exceeds five and a half millions, constituting a numerous family of children settled in life around one parent.

From the lowest depths of the ocean, the sounding-lead brings up to light numerous additional specimens of minute shell-fish, which adhere to the tallow affixed to the lower end of the plummet. Professor Bailey's microscopic examinations of the specimens of these fellow inhabitants of our planet, thus obtained from the deep ocean bed beneath the Gulf stream, demonstrate that "hundreds of millions of organisms of the calcareous polythalmia exist in every cubic inch of the specimens thus obtained."

In pools of fresh water are found equally numerous collections of organic remains of animalculæ of the minute species of infusoria, called the monadidæ, of the dimensions of only $\frac{1}{30000}$th of an inch.

In each cubic inch of a stratum of earth, of the extent of 14 feet in thickness, the celebrated Prussian microscopist, Ehrenberg, states there probably are deposited 41,000,000,000 of minute shells, or *shields*, of animalculæ; and the eminent American microscopist, Professor Bailey, of West Point, computes that the slimy mucous matter, floating on the surface of pools in boggy locations, as a film of iron rust, sometimes of the thickness of $\frac{1}{4}$ of an inch, contain about 10,000,000,000 of animalculæ in one cubic inch, being ten-fold more in number than the whole human population of the earth.

Organic Formations, constituted of the naturally *solid*, inorganic atoms of lime, or *calcium*, and of *silicon*, or siliceous minerals, such as bones, the enamel of the teeth, and the shells of various kinds of marine animals, and of the fresh-water class of infusoria, are not so prone to recoil from their solid groupings as the preceding organic formations, constituted of the fluid elements of carbonic acid gas and water. The organic remains of shells of marine animals found far inland, and in mountains ten thousand feet above the present level of the sea, demonstrate this fact. Some kinds of the white siliceous matter constituting the beds of swamps, are discovered, by means of the microscope, to be composed of the shells of classes of animals too minute to be detected by the naked eye. Animal organic formations constituted of these materials retain the impress of the static conditions impressed by life-power, unchanged during an incomputable period of time.

The thickest strata of the crust of our planet have been found to be *fossiliferous*, and in many places to be almost entirely composed of accumulated deposits of the organic remains of plants and animals. To the discriminating eye of the contemplative geologist, the crust of our planet, indeed, appears to be so full of the remains of organic formations, as to resemble one vast charnel-house.

Showers of dust have at various times fallen upon the surface of extensive regions of the earth, covering in some cases more than a million of square miles. Ehrenberg has detected, by the microscope, one-eighth part of the mass of some of this dust to be composed of the siliceous shells of infusoria, of which he has given drawings of 123 different shapes. The quantity of these organic formations frequently discharged upon the earth is so vast as to draw forth from this keen observer of minute objects the following exclamation: "With such facts before us, how many thousands of millions of quintals of microscopic organic formations have reached the earth since the time of Homer, who has given the earliest record of such an event!"

Assuming the number of species of living organic formations to be about 250,000, and the number of individuals of each species to be most of them estimated by billions, even the imagination becomes bewildered by the contemplation of the vast extent of animal life on the surface of the planet, on which we find ourselves existing. But when it is further considered that each one of the other planets of the solar system probably teems equally with living beings, and that there exist many millions of solar systems within the limited bounds visible by means of telescopes, constituting "our cluster of the heavens," we feel our powers of computation to be as completely incompetent to appreciate the probable number of intelligences, each animating distinct, independent bodies, as to appreciate the extent of infinite space and time.

CONSTITUENT ELEMENTS OF ORGANIC FORMATIONS.

By chemically analyzing the organic formations of some of the most important vegetable and animal substances consumed as food, they have been found to be composed of the three following proportionate groupings of organic formations, which have been denominated *Albumen*, *Fibrin*, and *Casein*, or cheesy matter.

Comparative Table of the Kinds of Elementary Atoms grouped into the Organic Formations of the Bodies of Plants and Animals.[*]

		ALBUMEN.		FIBRIN.		CASEIN.	
		VEGETABLES. Wheat.	ANIMALS. Blood, Eggs.	VEGETABLES. Juices of Plants.	ANIMALS. Muscles.	VEGETABLES. Various Seeds	ANIMALS. Milk and Cheese.
Carbon,		55 01	54.84	54.60	54.56	54.13	
Nitrogen,		15.92	15.83	15.81	15.72	15.67	
Hydrogen,		7.23	7.09	7.30	6.90	7.15	
Oxygen,	21.12	21.84	22.24	22.29	22.82	23.03	
Sulphur,	.37						
Phosphorus,	.85						
		100.	100.	100.	100.	100.	

The principal constituents of flesh and blood have been found by analysis to be the three preceding compound substances, *Albumen*, *Fribin*, and *Casein*. Although they present such a difference of characteristic properties as to entitle them severally to be considered as distinct kinds of compound substances, yet the relative proportionate groupings of their component atoms are almost precisely similar, as will be noticed on comparing the analysis of them contained in the preceding table.

By comparing the vegetable *albumen* of wheat, constituting the principal kind of the food of man, with that of the *blood* and the whites of eggs, they are found to be nearly identical in every particular.

From the *albumen* of the white and yolk of an egg, the latter of which also consists of albumen, with oily matter, the organic formation of a complete bird is produced, with all the distinct formations of feathers, horn, hair, blood, flesh, &c.

The original organic formation of *albumen* is accomplished only by the electro-dynamic action of the sun on the organs of plants; and, as Liebig affirms vegetable albumen to be "the true starting point of all the animal tissues," we are hence led to trace the physical "starting point" of animal organic formations to the original source of the electro-dynamic action of the sun on the mechanisms of the organs of plants.

The food of all animals contains this peculiar grouping of atoms into the modified, static condition of *albumen*. The nutritive value of most kinds of food is determined by the proportion of albuminous matter it contains.

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[*] Graham's Chemistry, p. 689.

Albumen is particularly distinguished from all other groupings of vegetable organic formations, by containing the extraordinary large proportion of about one-sixth part of atoms of nitrogen. The presence of the atoms of this kind of elementary matter serves to reduce the grouping of the other atoms, with which it is associated both in organic and inorganic formations, to an exceedingly delicate, constrained, static condition of equilibrium of opposite forces, from which such groupings are prone to recoil, either instantaneously, as in the fulminating nitrates of silver, of potash (saltpetre), of gun-cotton, &c., or more tardily, by the slower process of fermentation, as occurs in the decay or decomposition of all vegetable organic formations.

It may be ascribed to this fact (of the peculiarly unstable constrained static condition of the atoms of nitrogen in the composition of albumen) that it becomes practically an article of food, being more readily dissolved by the inorganic reaction in the process of digestion in the stomach, and by subsequently recoiling more readily to their original natural static conditions of carbonic acid gas, water, and ammoniacal gas.

The preceding facts demonstrate, that the process of *digestion* is a resolution and absorption of the groupings of vegetable organic formations, constituting food, into the fluid animal organic formation of blood.

To prepare food for undergoing the process of resolution into carbonic acid gas and water in the lungs of animals, it is shown by physiologists that there are necessary preliminary processes, or preparatory stages of reorganization of the particles, effected by the organs of the stomach and alimentary vessels. It becomes converted first into a species of milky pulp, which is poured into the arterial vessels containing the circulating blood.

By reference to the following comparison of the constituent elements of fibrin, or flesh and blood, and of bread, of which these organic compounds are mainly formed, it will appear that the only difference is the relative proportions of some of the ingredients.

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	
100 parts of FIBRIN or FLESH, and BLOOD, contain	53.3	7.2	19.6	19.9	
" " WHEAT or BREAD "	46.1	5.8	43.4	2.3	
" " BLOOD and FLESH "	7.2	1.4		17.6	more, and
			23.8	. . . .	less, of the

above specified kinds of elementary susbstances, than bread contains.

The fibrine, or muscles, constituting flesh, blood, albumen, and gelatin, are characterized by containing a larger proportion of nitrogen than either vegetable organic matter, or the animal organic matter constituting fat.

The uses of the last named substance appears to be expressly designed for subserving the simple purpose of reorganization into the first named substances, as constituting parts of real machines; or else to become burnt for the purpose of developing impulses of mechanical force adequate to operating the animal machinery.

Human flesh is nearly similar in its composition to that of the herbivorous ox and sheep, which are consequently readily reorganized into human flesh and blood; and human fat, hog's fat, and whale fat, are also almost precisely similar, as an inspection of the Table, page 110, will show. The deposits of fat are apparently designed to serve as a readily available store of food, provisionally secreted in the cellular tissues of the body in anticipation of a temporary failure of a supply of other provisions.

The production of fat in animal bodies is supposed to originate from starch or sugar, the composition of which is such, that when deprived of a portion of the atoms of oxygen, *fat* remains.

The transmutation of sugar and starch into fat, appears to be the result of the separation of a portion of the atoms of oxygen therefrom. Thus, as stated by Liebig, if from starch, composed of 12 atoms of carbon, 12 of hydrogen, and 10 of oxygen, we take 9 atoms of oxygen, there remain, carbon 10 atoms, hydrogen 10 atoms, and oxygen 1 atom, which is one of the chemical formulæ representing the compositions of fat.

In the incipient stage of the existence of animals, there is transfused from the parent stock into the mechanisms of their respective bodies in the nascent state, or into the egg in which most of the animal organic formations are developed, a sufficient quantity of organic food in the form of blood, or albumen, to be burnt in their respiratory organs immediately on their inhaling the first breath of the atmospheric air. The newly born calf is thus enabled to burn carbon to develope motive power sufficient to follow and keep pace with the rambling cow in the pasture; and the quail is enabled to exert fleetness of locomotive powers on breaking forth from the egg-shell.

Mr. Bennett states in his treatise on Domestic Fowls, that "some chicks begin to break the shell too soon; that is, before they have taken in the necessary provisions of food, by the yolk passing into their bodies through the navel-string. The chick, indeed, which comes out of the shell before the yolk is thus taken up, is as certain to droop and die, as a calf would do, without milk."

Common observation teaches us, that it is as necessary to supply slices of bread to the mouths of working men, as it is to supply billets of wood to the mouths of furnaces of working locomotive engines, to sustain the movements of their respective mechanisms.

AVAILABLE USE OF FAT IN THE ECONOMY OF ANIMAL ORGANIC FORMATIONS.

The extraordinary abundance of fat in the bodies of animals inhabiting the intensely cold polar regions may be philosophically considered as a surplus stock of fuel, to be burnt for sustaining animal heat and motive power. Without this internal resource, for a supply during periods when no other available supplies of food are procurable from external sources, the animals of the arctic regions would speedily become motionless and frozen, remaining like marble statues fixed on the surfaces of the fields of ice and snow.

A most remarkably abundant provision of groupings of atoms of carbon and hydrogen, in the form of the organic formation of fat and oil, is found stored up in reserve in the blubber, which envelopes the bodies of whales like a thick white blanket. The philosophy of this surprising provision of available food and fuel, accumulated in these huge fishes, admits of the following explanations.

It appears that whales, in ranging from one feeding-ground to another, sometimes have to cross broad oceans. Without an extraordinary supply of carbon, provided like a stock of coal in the bunkers of a sea-steamer for sustaining a continuous combustion during a long voyage, the whales might fail of exerting the motive power necessary to propel their great bodies through the waters of broad oceans.

Whales have been captured, from whose bodies more than a hundred barrels of oil have been extracted. As spermaceti and cetine contain above 90 per cent. of carbon and hydrogen, one of these fish, therefore, carries with him about ten tons of combustible fuel, which is ready at all times to become absorbed and burnt, whenever this leviathan of the deep desires to employ powerful impulses of locomotive force, and rises to the surface of the ocean to draw in a long breath of air, containing the supply of oxygen necessary to burn this supply of carbon, and to allow it to recoil to its natural static condition of carbonic acid gas. The more a whale exerts his locomotive powers, the oftener it is necessary for him to breathe, or "*blow*," as the whalers term it.

Amid abundant granaries, and well-stored market-houses, where there is little danger of falling short of a due supply of daily food, it is manifest that in the economy of the mechanics of nature, there is no real necessity for this extraordinary supply of a surplus stock of carbonaceous fuel enveloping the ribs of human beings. This surplus weight of fat in their animal mechanism resembles that of a surplus burthen of fuel carried by a sea-steamer, which is thereby incapacitated either for carrying freight, or for fleetness.

The hump on the back of a camel—the locomotive engine of the wide deserts of Africa and Asia, may be deemed by the superficial observer as a deformity, or as a sort of natural saddle, ready prepared to bear the impositions of loads of merchandise, and as thus stamping this animal as a "beast of burthen," apparently by the original design of the Creator. But this uncouth appendage, so far from being designed expressly for the purpose of a saddle, does really subserve the more essential purpose of a knapsack of provisions on his back, to supply from this superabundant deposit of fat, which principally composes this hump, the carbon necessary for propelling the locomotive mechanism of his body across wide wastes of sand, where no blade of grass is found to replenish his exhausted supplies of carbonaceous food. A surplus supply of water is similarly provided in the extraordinary sacs of his stomach, as a substitute for the tank appended to an artificial locomotive engine.

Adventurous mariners navigate their barks among the icebergs of the polar regions, to procure the valuable stores of fat organized into the bodies of the whale, of the seal and walrus, which they seize upon as spoils, to be transported to marts of commerce for distribution for the purpose of being burnt as fuel in lamps, instead of the lungs, for which purpose it was originally designed. Men eagerly strip off the prized furs and down from the bodies of the seal, of the eider duck, and of other animals, whose breasts, exposed to submersion in icy water, and to keen wintry winds, require these non-conducting coverings to sustain the electro-dynamic excitation of animal heat. These prized spoils of soft furs and down are appropriated as a covering to sustain the same genial excitation within the glowing bosom of the civilized belle.

In the colder bosom of an Esquimaux belle, residing in a crystal palace, and beneath a dome built of blocks of ice, not only are these soft external appliances of robes of furs necessary for sustaining a genial glow of life's warm current, but also the most extraordinary combustion, in her lungs, of this fat and oily food. One of these belles, according to Captain Parry's narrative of his voyage to the arctic regions, sipped the oil from an extinguished lamp, and received a tallow candle as an acceptable bon-bon, the courteous captain kindly enjoining upon her by signs, suiting the action to the word, not to choke herself by attempting to swallow the wick.

It thus appears that the quantity of organic carbon which is scarcely adequate to serve as fuel for developing warmth and locomotive powers in the bodies of human beings dwelling in the arctic regions, would overheat the bodies of the same individuals when transported to warm tropical climates, and would induce speedily fatal inflammatory disorders.

To the ignorance of this simple fact are ascribed the deaths of myriads of voyagers from cold to warm climates.

On the contrary, voyagers from sultry climes to cold regions require the combustion of more carbon in their lungs to sustain the average temperature of blood heat. Indeed, the sensation of a waning warmth is so immediately attendant on a waning supply of food, that the terms "cold" and "hunger" have become associated together; and the phrase "starving with cold," has become introduced into popular parlance in England.

As there is a greater tendency to an excess of animal heat in warm climates, this pernicious result is provided against, by the process of cooling the propagation of any excessive electro-dynamic action by the continual evaporation of perspired water from the surface of the body. The continual combustion going on in the lungs, and this continual evaporation of perspired moisture, produces the result of a delicate balance of temperature and of electro-dynamic excitation, which is uniformly maintained within a range of one or two degrees of the thermometer, as is commonly designated on the scale of the thermometer by the term, "blood heat."

Whenever this delicate balance of excitation of the body is not maintained, and an excessive excitation occurs by a quickened pulsation, and diminished evaporation, the phenomenon of the excessive heat of "fever" is manifest.

In cases of fever, the preceding analogies teach us that the rapid wasting away of the patient's body is an effect resulting from the combustion of the fatty matter, whereby the extraordinary heat of fevers is sustained. As fevers are usually attended with a checked perspiration and dry surface of the skin, there is reason for believing that a reversed action of the functions of the pores is induced, whereby the oxygen of the air combines with the carbon and hydrogen of the blood directly through the thin membrane, covering the external surface of the body, instead of being confined to the thin membrane lining the interior of the lungs. The effluvia from the bodies of patients during fevers, doubtlessly originate from the exhalation of carbonic acid and other gases through the skin instead of through the lungs.

The remarkable stimulating excitation of alcohol in the man system, is probably ascribable to the rapid decomposition or burning of this substance in the lungs. Alcohol is a vegetable organic formation, artificially arrested during the process of fermentation in its half-way recoil from its constrained static condition to the natural static condition of carbonic acid gas and water. This highly stimulating fluid exhibits a grouping of 4 atoms of carbon, 6 atoms of hydrogen, and 2 of oxygen, constituting an intermediate stage between food and fuel. To the extraordinary proportion of the grouping of atoms of hydrogen, contained in alcohol, which become united with thrice as much weight of atoms of oxygen during the process of combustion as carbon does, may be traced the peculiar excitation caused by this pernicious compound on the animal system. Instead of undergoing a protracted process of digestion, this fluid appears to become speedily assimilated as a sudden and excessive supply of combustible fuel to be burnt in the lungs, causing extraordinary developments of heat and of animal motive power, and a quickened pulsation, which surcharges the arteries of the brain, and deranges the functions of this organ.

According to recent observations, it appears that the supply of the groupings of the atoms of carbon burnt in the lungs, is principally derived from the modifying action of the organ of the liver in secreting the bile, which Liebig states is completely absorbed into the circulating medium of the blood, very little bile being discoverable in the fæces of healthy persons.

This theory of the combustion of the carbon of the bile serves to account for the disappearance of this yellow secretion in healthy persons by the resolution of it into carbonic acid gas, and the expulsion of it in the process of breathing it from the lungs. It also admirably illustrates the advantages of air and exercise in facilitating the combustion of the carbonaceous matter of the bile as fast as it is produced and poured into the system, and in thus preventing any accumulation of it in the system to induce excessive excitation or inflammatory action. In bilious disorders, the importance of a restricted supply of carbonaceous food, and a more rapid combustion of it by the quickened breathing, resulting from active labor, constitutes the true panacea of "diet and exercise" usually prescribed by physicians for the cure of bilious disorders. It is, in fact, the working off the high pressure steam of the locomotive when surcharged with readily combustible fuel. An over-wrought excitation, and an under-wrought action, is as dangerous in the one case as the other.

The excess of the carbon of the yellow bile is readily betrayed by the transparency of the skin; and it is commonly found that the most effectual cosmetic to restore a clear complexion is a vigorous development of animal motive power; to produce which, requires the thorough combustion of this sooty accumulation in the veins. The quickened circulation of the arterial system even brings some of the blood so near the porous membranes of the surface of the cheeks, as to become grouped there with the oxygen of the fresh air of the atmosphere, producing the rosy florid hue of the arterial flush, as contrasted with the blue color of the venous blood. Thus a partial recoil of the grouping of atoms of the organic formation of the blood, from their constrained static conditions to their natural static conditions of carbonic acid gas, may take place on the surface of the cheeks, exposed to the oxygen of the fresh air, consistently with vigorous health, whilst tempered by the cooling evaporation of exuding insensible perspiration; in the same manner as takes place in the lungs. And the thinness of the membranes covering the lips may allow of a similar partial combustion of the blood to take place there also, to produce the bright vermilion tints of arterial blood.

There is a pleasurable as well as healthful glow attending the development of animal motive power, excited by the free supply and combustion of carbon in the lungs, as manifested by the bounding movements of the healthful child, of the skipping lamb, and of the proudly prancing horse. Indeed, so far as health, and consequently pleasurable enjoyments are concerned, the decree ordaining that man should earn his bread "by the sweat of his face," is in strict accordance with the principles of the operation of the mechanism of his body.

When the body is fixed stationarily in any one position, as is common in many sedentary branches of human labor, there is not the designed extent of animal motive power developed, which is requisite to exhaust the accumulated stock of fuel in the blood. As if by natural instinct, to accomplish this result, most persons employed in such constrained vocations may be seen to exert some peculiar action of the muscles, by occasionally swaying their bodies, or their limbs, to and fro. Compositors may sometimes be noticed mechanically nodding their heads, as if in token of familiar recognition to every type they pick up. Wild animals, confined within the narrow cages of menageries, relieve themselves of the inactivity, consequent on their confinement, by incessantly swaying their bodies, or pacing back and forth. The common habit of the vibrating movement of the foot, the process of yawning, and the use of rocking-chairs, are so many illustrations of the truth of the preceding principles.

The wealthy and the luxurious, who are exempted from the necessity of daily labor, are commonly found to suffer more from bilious disorders and plethora; and, on the other hand, it may sometimes afford philosophical consolation to those whose tables are scantily supplied with luxurious food, to recur, in memory, to the *Table*, at page 110, of the constituent elements of the Organic Formations of Food, as a sort of bill of fare. This Table satisfactorily shows, that even cold potatoes and cold bread contain a plenty of organic carbon to fire up with; and that all kinds of vegetable organic formations are nearly the same things; whilst at the same time the soothing reflection may steal consolingly over the mind, that turtle-soup and roast pigs, in their excess of atoms of nitrogen, as in the excess of the same atoms in the nitrates or fulminates of different metals, are dangerous, explosive things, producing risks of the bursting of blood-vessels by apoplexy—a fearful blow-up of the animal mechanism.

The preceding recapitulation of facts relating to the immediate causes and modes of action of animal motive power, all tend to demonstrate, that a vigorous and healthful condition of the animal mechanism can only be sustained by a due relative apportionment of the supplies of organic carbon and hydrogen, presented in the thin membranous air-vessels of the lungs, to the contact and union with a due relative apportionment of atoms of the oxygen inhaled at every breath, and by the appliances of non-conducting clothing, to prevent the too rapid propagation of this electro-dynamic excitation of the body. And thus the mechanical motive-power of the vital agency, or "life," truly subsists by the combustion of carbon, in accordance with the emblematical flame of the lamp, which was once lighted in every tomb by a classic, superstitious people, as allegorically representing the bright spirit which for a brief time animates the body, and then vanishes for ever, like the quivering and expiring blaze.

The Animal Organic Formations, after the controlling sceptre of the life-power is stricken down by death, yield to the subsequent paramount control of the Inorganic Action, as before recapitulated. Then the beautiful and wonderful mechanisms of all such animal organic formations begin loathingly to recoil to their natural static conditions of invisible gases and vapor of water, leaving behind only a little solid lime-dust, as "the ashes of the dead."

ON THE POSSIBILITY OF ARTIFICIALLY PRODUCING GROUPINGS OF ATOMS, WHICH WILL SERVE AS A SUBSTITUTE FOR VEGETABLE ORGANIC FORMATIONS OF FOOD FOR ANIMALS.

Notwithstanding chemists can decompose the various compound substances constituting food, and obtain the separated elementary atoms, yet, no human art can recombine them, and reproduce the same grouping, to subserve again the purpose of food, unless by means of recourse to the electro-dynamic action of the sun on the organs of plants. However the very same atoms of carbon, hydrogen, oxygen, and nitrogen, may be commingled, and treated by the most scientific manipulations of the laboratory, yet no grouping of them can be obtained which will exhibit the characteristic properties of a grain of wheat, or of a fibre of wood.

A great variety of interchangeable combinations of certain groupings of the atoms of the organic elements may be artificially produced; but an original organic formation has never been artificially produced. Vegetable fibres of wood have been converted into a new compound having the taste, and some of the properties of sugar; and to turpentine, some of the characteristic properties of camphor have been imparted. At one time German chemists hoped to succeed in transmuting resin into butter; but alas, the scent of the resin would "hang round it still."

Chemical skill, in the manipulations of the laboratory, has proved successful in producing artificial groupings of atoms of inorganic matter, which exhibit some of the characteristic properties of natural groupings of organic matter, elaborated by the agency of living plants whilst excited by the sun. It may be asked, is it not within the bounds of possibility, that chemists may yet discover artificial processes for producing such an imitation of the groupings of atoms of carbon, hydrogen, oxygen, and nitrogen, as may subserve the purposes of food in exciting animal heat, and animal motive power? May not the chemist in his laboratory discover processes whereby he may compete with the agriculturist in his sunny fields, in reducing to similar temporary constrained electro-static conditions of groupings, the same kinds of elementary atoms which constitute food and fuel?

No discovery in chemical science has as yet afforded a hope that a grouping of elementary atoms may be artificially produced, which will dispense with the necessity of a recourse to the organs of plants acted upon by solar excitation; for it is the excitation of organic action which sustains constrained static conditions of grouping of elementary atoms, that develope the available dynamic properties of substances constituting food. If human skill could succeed in artificially establishing constrained static organic action in connection with groupings of simple elementary atoms,—of carbonic acid gas and water,—it would be but another step to control this organic action to the production of vegetable organic formations. The art of chemistry has recently succeeded in effecting the decomposition of carbonic acid gas, which is so readily and universally accomplished by the mechanisms of the organs of plants by modifying the propagation of the electro-dynamic action of the sun.

So remarkably similar are the characteristic properties of some of the chemical groupings of elementary atoms effected artificially, and some of the groupings naturally effected by the agency of the organs of animals and of plants, that Professor Liebig has been led boldly to affirm, that "the power to effect transformations does not belong to the vital principle; but that each transformation is owing to a disturbance in the attractions of the elements of a compound, and is consequently a purely chemical process."

There is a wide distinction between a *purely chemical process*, as affirmed by Liebig, and the process of effecting organic transformations by the vital, or zoödynamic agency; for the latter, instead of grouping together atoms, generally, in obedience to the laws of chemical affinities, collects only certain specific kinds of elementary atoms, as if with scientific knowledge of their respective chemical properties, the most perfectly adapted for accomplishing the particular purposes for which they are employed in animal mechanisms. The transformation of the materials contained in the blood of animals into the phosphate of lime, constituting the enamel of the teeth, must be due to a vital principle, in the constitution of which there is manifested a perfect knowledge of chemical affinities, by the selection of this most suitable compound for resisting not only the mechanical action of attrition, but also the chemical action of the acids and alkalies, with which the teeth are so frequently brought into contact in the varieties of food subjected to mastication. Indeed, the transformations of the atoms of carbon, hydrogen, oxygen, and nitrogen, into the groupings of the bodies and seeds of plants, so far from being a chemical process, is positively effected in despite of chemical affinities. All organic substances are in a temporary constrained electro-static condition, from which they spontaneously recoil in obedience to chemical action, which we have denominated Inorganic reaction to the paramount Organic action when allowed freedom of motion; as has been repeatedly stated of the process of fermentation and combustion of organic formations of food and fuel.

By means of artificial processes of the laboratory, it is true, chemists are able to produce groupings of atoms of certain organic formations into a large number of new compounds, similar to the organic compounds directly produced by the agency of the zoödynamic powers of plants and of animals; such, for instance, as the various kinds of vegetable and animal acids. Among these may be recapitulated oxalic, benzoic, formic, butyric, lactic, margaric acids, &c. It is equally true, as stated by Dr. Turner,* that the "oil of mustard, and oil of garlic, besides many substances of analogous properties and composition, are artificially producible, which are not yet known to occur in natural products.

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* Turner's Chemistry, page 1308.

The number of the substances connected with the organic world, which can be formed artificially, is rapidly increasing, and our new methods approach far more nearly in their principles, as well as in their results, to the processes of organic life, than was supposed possible a few years since. It is now quite conceivable that we may discover the means of producing, for•example, a body having the composition and chemical properties of albumen or gelatine. But there is no reason, derived from our present state of knowledge, for thinking, that we shall ever be able to give to such a compound the form of an organized tissue."

In producing these results of artificial imitations of compound organic substances, it is to be remembered that the manipulations are commenced by regrouping atoms already reduced to the constrained static conditions of organic formations, by the previous action of the sun on the organs of living plants.

Mankind, therefore, are reduced to the necessity of seeking out and cherishing on every sunny hill side, and in every fertile vale, the kinds of plants whose mechanisms most effectively serve to modify the propagation of the electro-dynamic action of the sun, to collect and organize carbonic acid gas and water into food. The term Planter, has hence become incorporated into the language of every civilized nation. The principal occupation of mankind is labor in the fields, to extend the propagation of plants. The knowledge of the most effective modes of accomplishing this result constitutes the science of AGRICULTURE.

The most essentially valuable property possessed by mankind is the individual right of appropriating the exciting action of the sun, incident on fields abundantly supplied with the elementary atoms constituting water and carbonic acid gas, which may there, with the greatest facility, be converted into vegetable organic formations of food.

ESTIMATION OF THE VALUE OF SUBSTANCES, AS MERCHANDISE, TRACEABLE TO THE ELECTRO-DYNAMIC ACTION OF THE SUN ON TERRESTRIAL MATTER.

The principal value of the groupings of atoms into both inorganic and organic substances, constituting the merchandise interchanged between men, are based on their several dynamic properties, as of cohesion of steel, iron, wood, hemp, cotton, flax, leather, &c.—as well as the above described dynamic properties of food and fuel. A few of the facts which demonstrate the preceding statement will be briefly adduced, to show that there is no fiction in ascribing all human estimates of terrestrial values of elementary matter to one common originating mechanical cause of natural motive power, situated at the distance of ninety-five millions of miles.

When we behold the vast ranges of warehouses of great cities filled with accumulated quantities of flour, rice, corn, sugar, &c., and the extensive market-houses filled with flesh, fish, and vegetables;—the piles of bales of cotton, wool, hemp, flax, tobacco, leather, wood, coal, metals smelted by the combustion of fuel, timber, boards, &c., we realize the importance to the well-being of mankind of the *organic* forces established in connection with these diversified static conditions of groupings of atoms.

Even the "precious" metals constituting the *inorganic* substances of gold, silver, platinum, and it may be added copper, all owe their relative rank in human estimation to the pertinacity with which their component atoms retain their natural static conditions of groupings unchanged, as they have existed in the earth since their creation. And the most precious of all groupings of atoms, the diamond, eminently takes the lead of other substances for its extraordinary dynamic powers of propagating the electro-dynamic action of the sun to the material nerves of the eye in the modified form of sparkling light, as well as for the extraordinary mechanical fixedness or hardness of the groupings of its component atoms.

By tracing out these analogies, it will be found that every kind of substance prized as a valuable article of commerce, owes its estimation to some peculiar availability that has originated from the propagation of the electro-dynamic action of the sun to terrestrial matter.

The production, preparation, and interchanges of these various formations constitute the principal absorbing business labors of civilized man in the three great leading pursuits of *Agriculture*, *Manufactures*, and *Commerce*.

The *Agriculturist* devotes himself to collecting and exposing the cereal and other germs to the electro-dynamic action of the sun, where carbonic acid gas and water have the most abundant access to their roots and leaves, through the mechanisms of which the solar action reduces these fluid formations from their natural static conditions of groupings, to the constrained static conditions of the solid organic formations constituting food. He has recourse to the agency of the mechanisms of the organs of the plants of flax, hemp, and cotton, to render available the electro-dynamic action of the sun for establishing among the groupings of the same atoms of carbonic acid gas and water, new and valuable properties of electro-static conditions, in the modified form popularly recognized as the cohesive strength of hempen cables, and of filaments of flax and cotton. Or he may cause his crops of grass to become reorganized into the bodies of sheep and oxen, constituting food, or into similar cohesive fibres of wool, hair, and leather; or otherwise, he may cause his hay to be burnt as fuel in the lungs of his horses, to develope available animal motive power.

The flocks and herds, with their endowments of instincts and self-directive motive powers, devote their time and labor to gathering from hill and dale various species of vegetable organic formations, even to gleaning each scattered spire of grass from the road-side, and from the cliffs of the mountain-side, that no organic formation, constituting food, may be wastefully lost in the economy of nature.

The *Manufacturer* devotes his skill and science to the preparation of these various organic and inorganic groupings of atoms into the most available forms for use as food, clothing, shelter from the weather, machines for facilitating the transportation of these products of the electro-dynamic action of the sun in ships on the ocean, and in cars on the land, &c.

The *Merchant*, in turn, takes charge of these interchanges of organic and inorganic formations between the inhabitants of the same country, and of distant shores.

The inability to command the use of these necessary appliances for sustaining the electro-dynamic excitation of animal warmth and of animal motive-power, is denoted by the term *poverty*.

The individual command of an excess of these electro-dynamic appliances is deemed to be the possession of *wealth*.

The hopes and fears connected with the procurement of these necessary appliances for sustaining the excitation of animal warmth, and of animal motive-power, constitute the absorbing cares of *business*.

In connection with these investigations of the physical powers of animals, it is to be kept in remembrance that they are subordinate to an immaterial essence of an intellectual nature.

It is too commonly the case, that civilized men become so much absorbed by the business cares of procuring these various appliances of organic and inorganic formations, that the undivided energies of their minds are devoted, from their earliest days to their final hour, to the sole purpose of providing the means of commanding the use of them abundantly, and even to provide stores of them in anticipation of the wants of their posterity. The cultivation and exercise of the higher faculties of the mental powers are commonly devoted as entirely to this subserviency to the physical powers, as if the former were originally designed merely to be subservient to the latter; as is apparently the case among savages dependent on the fortunes of the chase. And it too commonly occurs, that men are held in estimation according to their acuteness in successfully winning appliances for sustaining a physical existence, rather than for successfully using these appliances subserviently to the final, nobler purpose, of relieving the mind from such absorbing cares, to allow of cherishing the more elevated developments of the god-like, intellectual, and moral powers.

The final design of mechanical philosophy is to provide appliances adequate to relieving the mind from the too absorbing cares of life, and a too exclusive devotion to an incessant watchfulness, like that of the Roman vestal virgins, solely to maintaining the vital flame on the temple altar. The immaterial essence of the mind has its peculiar wants and appetites to be ministered unto, as well as the organic mechanism of the material body, in order to render their connection reciprocally pleasurable and happy.

As ample means are provided by the Creator for the refined, intellectual enjoyments of the former, as for the grosser, physical enjoyments of the latter. Precisely as man learns by mechanical and moral philosophy to apportion to each its proper and peculiar aliment, he is enabled to enjoy the greatest degree of happiness that is compatible with the association of a spiritual with a material nature—of a sound mind with a sound body.

As the infringement of the physical laws that govern the mechanism of our organic frame-work produces the result of the penalty of bodily pain, so the infringement of the moral laws that govern our spiritual being, produces a similar result of mental pain. The penalty of the suffering of pain, which is commonly considered an "evil," was considered by one of the most eminent of the ancient philosophers, Euclid, as designed benevolently to admonish men of their errors and ignorance of natural laws, and to warn them to acquire the "knowledge to direct them in the path most conducive to their happiness."

Indeed, so intimately associated is the progress of physical science with that of moral science, that unless they keep pace with one another in their advancement, the value of the former becomes lost. Far better would it have proved for man, to have continued to live dependent on his precarious, original avocation of a hunter in the forests, or on that of a simple shepherd, with his mind solely devoted to the procurement of his daily food and raiment, than to allow the mind, after being relieved from such absorbing pursuits, to become idly devoted to indulgences in debasing propensities.

Beneficence being the manifest design of the Creator in establishing finite intelligences in connection with the organic formations of the mechanisms of animal bodies, every investigation teaches us that this connection can only be attended by happy results, when this original design is regarded as the governing principle of both an intellectual and physical existence.

Our prescribed limits will not admit of pursuing further these interesting investigations of the final designs of the groupings of atoms into relative states of rest, or *Static* conditions of solid Organic and Inorganic Formations.

It will be sufficient for our present purpose, if we have succeeded in establishing as a law of science, that mechanical groupings of atoms into all Inorganic and Organic Formations serve to maintain between them, reciprocally, the continuous propagation of the electro-dynamic action of the sun in variously modified directions, so as to produce the continuous constrained *static* conditions of their aggregations into discoverable magnitudes and masses; and to develope a *resultant dynamic* action on every change of such groupings from one static condition to another.

Having thus completed a brief recapitulation of the facts of the natural groupings of atoms into *Static* conditions, constituting the first grand sub-division of the science of the mechanics of Nature, our attention will now be turned to the investigation of the second grand subdivision of *Dynamics*, constituting the resultant action developed on every change of the groupings of atoms from one static condition to another.

DYNAMICS OF THE MECHANICS OF NATURE.

> "All our perception and knowledge of the atom, and even our fancy, is limited to ideas of its powers."—FARADAY.

HAVING considered Organic and Inorganic formations to be mechanical effects of the groupings of atoms, produced and sustained by the continuous action and reaction of counterbalanced impulses of mechanical force, we shall classify the antagonistically directed impulses producing these two opposite kinds of static conditions, by the conformable terms of INORGANIC ACTION and ORGANIC ACTION.

The mechanical impulses producing the groupings of atoms of all kinds of terrestrial matter into inorganic formations, such as those of vapory thunder-clouds, steam, and solid crystals, have been shown to originate from the electro-dynamic action of the sun continuously propagated in variously modified directions between the centres of the approximated atoms. The mechanical impulses producing the grouping of a few kinds of elementary atoms into the organic formations of vegetable and animal bodies, have also been similarly shown to originate from continuous propagations of the same electro-dynamic action of the sun, modified by the mechanisms of living organs.

The term, Inorganic Action, will be used in our future investigations to denote the continuous propagation of the electro-dynamic action of the sun between atoms, grouped into all kinds of Inorganic formations of lifeless terrestrial matter; and the term Organic Action will be used to denote the continuous propagation of the same electro-dynamic action between a few kinds of elementary atoms, as modified by the paramount influence of the organs of living plants, or by "*vitality.*"

The distinction which the science of mechanics recognizes between Inorganic and Organic actions, consists simply in the difference of the relative directions of the impulses propagated between the groupings of atoms, to produce the two peculiar arrangements of them into Organic and Inorganic formations.

The propagation of mechanical impulses in variously modified directions between different masses of atoms constitutes the clearest conception we are able to form of the functions of machines. Every engineer, in contriving a machine, has always in view modifications of the relative directions and intensities of the propagation of mechanical impulses through the medium of the masses of atoms constituting the respective parts. So in considering all groupings of atoms of Inorganic and Organic formations, we shall regard them as so many distinct kinds of natural mechanisms, each specifically constituted for modifying the relative directions and intensities of the propagation of electro-mechanical impulses through their respective parts.

To the specific powers of different groupings of atoms in modifying the propagation of the electro-dynamic action of the sun, rather than to any supposed existences of "imponderable agents," or of "inherent forces" innate in matter, we shall direct our attention in the following pages.

The groupings of atoms of lifeless matter into Inorganic formations, are found to propagate electro-dynamic action between their respective centres at insensible distances, and between masses at sensible distances, in *three determinate directions.*

Inorganic action moves bodies reciprocally,

Toward each other's centres, as popularly denoted by the general term of ATTRACTION of	Electricity, Magnetism, Chemical action, Cohesion, Gravitation.
From each other's centres, as popularly denoted by the general term of REPULSION of	Electricity, Magnetism, Chemical action, Heat.
About each other's centres, as popularly denoted by the general term of POLARITY of	Magnetic bodies.

Organic action moves bodies reciprocally in every direction in relation to each other's centres.

The mechanical effect of the falling of a stone, and the cause of the impulses producing this effect, are both denoted in popular works on natural philosophy by the same term, "Gravitation;" and both the cause and the effect of the mechanical impulses producing the groupings of atoms into solid bodies are also denoted by one and the same term, "Cohesion." The term "Attraction" is employed in common to denote both of these mechanical causes and mechanical effects. There has been introduced into treatises on the physical sciences a bewildering blending of ideas of causes and of effects of impulses of mechanical force. The employment of the same term, "Attraction," to denote both causes and effects, as Berkeley has observed, "may be used in compliance with custom, where motion alone is meant;" but "*Attraction* cannot produce, and in that sense cannot account for the phenomenon, being itself one of the phenomena produced and to be accounted for."

It follows as a consequence of the variously modified changes of the directions and intensities of mechanical impulses interchangeably between groupings of atoms of Inorganic and Organic formations, that such impulses may be either antagonistical to each other, or coincident with each other, according to contingent circumstances, so as to produce every variety of static and dynamic conditions of groupings of terrestrial matter, as detailed in the two subdivisions of "Inorganic" and "Organic chemistry."

As observed by Liebeg, "in all organic compounds it is necessary to consider two kinds of attractions, that of contained radicals, and that of the ultimate elements themselves for each other."

The preceding classification of the modified propagation of the electro-dynamic action of the sun between portions of terrestrial matter into Inorganic and Organic action, although hitherto overlooked in treatises on the science of mechanics, has been practically adopted in the science of chemistry, by classifying "chemical action"—the dynamics of this branch of science—into the two preceding great subdivisions of Inorganic and Organic chemistry. But the causes of the propagation of the mechanical action producing changes of the groupings of atoms denominated "chemical changes," are ascribed by chemists to various "agents," such as the *imponderable agents*, "heat," "light," and "electricity," and to *ponderable agents* of a uniform character, such as atoms of oxygen, hydrogen, carbon, &c., variously grouped to exhibit the properties of acids and alkalies.

In qualitative analysis the term "re-agents" is employed by chemists to denote the acids and other tests used to produce the "repulsion" or mechanical reaction between compound groupings of elementary atoms.

In defining the chemical relationships of the atoms of matter, Dr. Hare observes, (page 1st, 4th Edition of Chemistry,) "in mechanics, action is said to produce re-action; but in the case of an innate property, which mutually causes different portions of matter to be self-attractive or repellent, it is impossible to distinguish the agent from the re-agent."

It is manifest that all the phenomena of *attraction* and *repulsion* producible both by the "imponderable agents" and by "chemical agents and re-agents," are mechanical effects of the approximation and separation of atoms produced by mechanical impulses; and as mechanical impulses have been shown to be identical, however produced or modified, all these different "agents of nature" become resolvable, not into causes of natural motive power, but simply into powers of modifying the direction of the propagation of natural motive power, as denoted by the preceding definition of the terms inorganic and organic action.

The preceding classification of dynamics into the subdivisions of inorganic and organic action, is more essential to the due consideration of the facts and principles of the science of mechanics than of the sciences of chemistry and geology; for these latter are merely descriptive sciences, confined to details of the mechanical effects of motive power as exhibited in the groupings of atoms into various static conditions, denominated "geological formations," and "chemical combinations." The science of mechanics, on the contrary, is appropriately devoted to the consideration of the causes and modes of action of the forces which produce the relative state of rest and motion of all terrestrial matter.

The tardy progress in establishing on an harmonious basis the sciences of mechanics and of chemistry, appears to be ascribable to a backwardness in applying the laws of the former science to explaining the phenomena of Inorganic and Organic chemistry.

On the other hand, the equally tardy progress made in establishing consistent principles of the statics and dynamics of the science of mechanics, may be ascribed to a neglect of the application of the facts of chemical action developed by the discoveries of chemists. Although "chemical action" may occur only between atoms at "*insensible* distances," yet it is ever to be kept in mind, that the same cause of mechanical action, which determines the relative states of motion and rest of every atom of masses, must determine the static and dynamic conditions of the whole of all the masses composed of such atoms; for whatever controls all the parts must unavoidably control the whole.

The preceding details of the universal diffusion of electric matter—of its subtilness, perfect mobility, and perfect capability of propagating impulses with inconceivable velocity to the remotest distances, as well as between atoms at insensible distances, have been recapitulated for the special purpose of demonstrating that this subtile fluid matter constitutes the real final medium for propagating impulses of mechanical force.

The fact of the imponderability of electric matter has been previously accounted for. It will better prepare us for the investigations on which we are about to enter, to take a preliminary glance at the—

REASONS FOR THE INVISIBILITY AND IMPONDERABILITY OF ELECTRIC MATTER.

The necessity of the employment of an invisible subtile medium to subserve the purpose of controlling the states of motion and of rest of the minutest atoms of matter, as well as of the masses of them constituting the huge worlds of the universe, will appear sufficiently manifest, if we imagine for a moment, that in place of the subtile agency of electricity, there were substituted the gross and palpable materials of chains, ropes, beams, and wheel-work, such as men ordinarily employ in the construction of an orrery.

The most massive chains would be required to restrain the movements of the planets to their circular orbits. And in order to confine the loose particles of sand and masses of rocks, and the fluid drops of oceans and lakes, to their places on the surface of the earth, in resistance of their tendency to move in straight courses in obedience to "centrifugal force," a perfect net-work of ties and ligaments crossing each other in every direction would be requisite on the earth's surface. The bulk of this machinery would far transcend that of the orbs of matter maintained in harmonious motion thereby. The beauty of every landscape view would have been so obstructed and obscured by such gross palpable fixtures, that no animal could have had free scope for viewing the earth's surface, or even for moving upon it; whereas impulses of mechanical force are propagated by electro-dynamic agency without causing the feeblest insect to droop his wings during his summer evening flight, by interposing any material obstruction in his course through the air. So perfectly subtile and undiscoverable, indeed, is this electro-dynamic action, that it requires the exercise of the keenest powers of human perceptions to detect the modes in which it is propagated. No noise of the clanking of chains, or of the rattling teeth of wheel-work is ever heard to interrupt the silence of nature. No sounds, save the rustling of the leaf by the winds, or the murmur of a waterfall and of ocean waves, or the occasional crashing thunder-peals,—all induced by the silent action of the cause of solar excitation, as has been recapitulated, ever break upon the listening ear, or reveal the agency of the subtile wonder-working "golden chain, whose strong embrace holds heaven and earth, and main." It even requires the aid of philosophy to render mankind aware of the facts of the incessant propagation of the continuously-repeated impulses of mechanical force, so quietly do they actuate the mechanisms of all parts of the universe.

For these special reasons it is important, in this preliminary stage of tracing out the modes of propagation of impulses of mechanical force through the medium of electric matter, to examine first the nature of the standard tests, which are relied upon by human intelligence for determing the truths of all the physical sciences.

STANDARD TESTS OF PHYSICAL SCIENCE.

"The only source from which we can draw a knowledge of nature is the perception of the senses."—MULLER.

FROM what has just been premised of the exceeding subtilness of the propagation of impulses of mechanical force through the medium of electric matter, it may be anticipated that the electroscopic mechanisms contrived for the purpose of detecting slight electric action, must necessarily be of a very delicately sensitive character. And when it is further considered that these material electroscopic mechanisms are designed to propagate action to affect an immaterial essence constituting the tribunal of human intelligence, located as it were on a judgment seat in the organ of the brain, the very idea of mechanically accounting for this mode of connection between mind and matter is precluded.

The laws of mechanical science establish that there can be no action without a reaction. Between a material and immaterial essence, there can be no action and reaction; and consequently here the lights of mechanical science can shed no gleam to render comprehensible the connecting link between mind and matter. A veil of mystery conceals this connection. Although the mind, like a perfect mirror, receives and reflects images of all objects of the external world, it shadows forth no outline of its own form of existence. And yet the mind realizes that it is possessed of an independent physical control of the power of receiving impressions from objects of the external world, and of exciting energetic impulses of mechanical force through the medium of organic action developed by mechanism in which it is emdobied.

It appears to have been a prevalent opinion from the earliest history of science, that the control of the volitions over the movements of the mechanisms of animal bodies is due to the intermediate agency of electricity. One of the most ancient and distinguished writers on the subject of physiology, Galen, taught, "that admitting the soul to be incorporeal, it hath for its immediate tegument, or vehicle, a body of ether or fire, by the intervention whereof it moveth other bodies, and is reciprocally affected by them. This tunicle of the soul, whether it be called pure ether, or luciform vehicle, or animal spirit, seemeth to be that which moves and acts upon the gross organs, as it is determined by the soul; from which it immediately receives impressions, and in which the moving force truly and properly resides."

This original supposition of a sagacious man appears to become verified, by every step we advance in tracing out the connections between the immaterial essence of the mind, and the elementary matter in which it is embodied. It is both a beautifully poetical, as well as philosophical idea, to consider the minds of intelligent beings to be enthroned in an atmosphere of "pure ether," as if too refined for immediate contact with the gross matter in which it becomes embodied during its brief existence on earth; and to be endued, like the fable king of the heathen gods, with the power of wielding this "luciform vehicle," as the sceptre of the physical control of mind over matter. Many facts still remain to be discovered before this subject of the influence of electricity in propagating action between mind and matter, can be clearly developed and rationally explained.

In the following investigations speculative theories will be studiously avoided, and demonstrable facts carefully adhered to.

In the absence of all known or discoverable uses of the mass of cellular substance constituting the organ of the brain, occupying the most important portion of the bodies of animals, and also of the uses of the nerves extended therefrom to every part of the body in regular pairs and circuits, like telegraphic wires, we can but consider them as specially devised mechanisms, to be acted upon by electricity. There is no escape from the conviction that the material nerves, like conducting wires, subserve the purpose of propagating comprehensible electro-telegraphic signals interchangeably between objects of the external world, and the matter of the brain.

The elements of matter, which are exalted to the distinguished eminence of forming the material throne of the mind, are found by analysis to consist of a combination of atoms of carbon, hydrogen, nitrogen, and oxygen, with a trifling proportion of sulphur and phosphorus. This grouping of atoms presents to view a mass of white fatty matter, having a curiously radiated structure, which has not been clearly traced out; nor has its mechanical functions been explained.

The grouping of atoms constituting the brain are resolvable into the following substances, according to Vauquelin's analysis:—

Albumen, ...	7·0	parts.
Fatty matter, ...	4·6	"
Phosphorus, ...	2	"
Sulphur, salts, and acids,	6·4	"
	20	
Elements of water, . .	80	
	100	

Thus it appears that four-fifths of the human brain is constituted of the elements of water. "This is the best account," as observed by Dr. Hare, "which it has hitherto pleased God to enable the brain of man to give of its own chemical constitution."

The bulk of the brain of a man, of the modern Caucasian race (including Anglo-Americans), averages from 80 to 92 cubic inches, according to Dr. Morton's experimental observations. The quantity of the human brain, as compared with that of the spinal cord, is in the proportion of 23 to 1; whilst the brain of reptiles is only in the relative proportion of 3 to 1, and of fishes as 2 to 1, according to Müller's observations.

Phrenologists have taken up the investigation of the mechanical arrangement of the brain, with the view of pointing out the specific portions of it in which reside the distinct causes of the moral impulses or sentiments; and of assigning to each moral sentiment "a local habitation and a name." Volumes have been written to establish various fanciful theories; and speculative men appear to have boldly disregarded all physical limitations to hypotheses, which do not admit of being established by material facts and mathematically exact analyses. They thus elude direct refutation by these trial tests of truthfulness.

Between the brain and the muscles, according to Sir Charles Bell's statement, there are established regular circuits of nerves, "one set of nerves serving to convey the influence from the brain, and another giving the sensation of the condition of the muscle to the brain,"—the former serving to transmit the exciting cause of contractions, and of consequent motive power to the muscle, and the latter to transmit from the muscles to the brain the action excited therein by external causes.

If one set of these nerves be cut off from its connection with any one of nearly 450 muscles of the human body, the communication between the mind or volitions, and the muscle connected with such nerve, becomes simultaneously cut off; and the mind is no longer able to excite and control the organic action developable in the muscle by its contraction. And if the other circuit of the nerves be cut off, the mind is no longer able to receive impressions or sensations from the organic forces excitable in the muscular organic formation, by the presence or contact of surrounding objects. Hence it has been concluded that the mechanical effect of muscular contractions is produced through the material agency of one order of nerves, intermediately acted upon by some cause of organic action, controlled by the mind or volitions; and that in like manner the electro-dynamic action exerted by any cause external to the body, to act on the organic formations of animal mechanisms, is transmitted through the medium of the other set of nerves to the tribunal of intelligence—the mind.

The nervous arrangements of fine thread-like substances are traceable as systems of telegraphic wires, radiating from the mass of white cellular substance, constituting the brain. This organ is incased in a cell of solid bone, or otherwise arranged in the most favorable locations in the several kinds of animal mechanisms for securing its safety from violent shocks, and other destructive causes of injury to its structure.

These facts prove the brain to be the prime central point of communication between mind and matter, and the most important part of the mechanism of every animal body.

All parts of the bodies of animals are found to be contrived for performing certain specific mechanical functions, except the brain; which performs no discoverable mechanical functions. It has hence been universally admitted that the sceptre of control of mind over matter is wielded originally from a throne of power in the locality of the brain. And in this locality is also supposed to exist the discriminating intelligence, to which, as to a judicial tribunal, the electro-dynamic action transmits impressions or sensations, which are there adjudged to be the characteristic properties of the matter of the external world.

The terminations of the nerves of sensation, which serve to propagate the electro-dynamic action from the external parts of the body to the brain, termed the sensorial nerves, have been found by Mr. Smee's experiments to propagate electro-dynamic action toward the brain; and the motor nerves and muscules serve also to propagate therefrom the same electro-dynamic action. Thus the sensorial nerves may be regarded as the wires which propagate the electro-telegraphic communications of the state of the external parts of the body and of the excitable organs, to the tribunal of human intelligence in the brain; and the motor nerves, on the contrary, serve to propagate the electro-telegraphic action to the muscles, and through their agency to the matter of the external world.

The organ of the brain has been considered as divided into *five* distinct circuits, each one of which constitutes a distinct galvanic arrangement, propagating electro-dynamic action from the muscles to the brain in one direction, and from the brain to the muscles in an opposite direction, to produce muscular contractions and animal motive power. These spasmodic contractions produce the development of animal motive power in every one of the muscles.

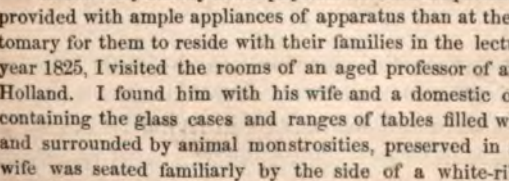
The artificial propagation of electro-dynamic action through any of the motor nerves produces muscular contractions. Hence, involuntary muscular contractions in living bodies, or in recently dead bodies, is deemed to be one of the most delicately sensitive electroscopic tests of electric excitation.

MOTOR NERVES AND MUSCLES OF ANIMALS CONSIDERED AS TESTS OF ELECTRIC EXCITATION.

The action of electric shocks on the nerves of sentient beings is too familiarly known to require minute description here. The animal muscles are caused to become violently contracted by the propagation of electro-dynamic action through them. Several hundred persons, forming one continuous electric circuit, by the contacts of their hands, have been simultaneously shocked by the discharge of a Leyden jar.

It was the electroscopic convulsive twitchings of animal muscles, which first awakened human attention to the new science of electro-dynamics. The merit of this original discovery appears to be really due to the quick intelligence of a sagacious woman, employed in the manipulations of the art of cookery. The wife of Galvani, a professor of anatomy at Bologna, was engaged in dressing the legs of some recently killed frogs, at the same table in a lecture-room where a student was experimenting with an electrical machine. She noticed that the legs of one of the frogs, lying in contact with the blade of a knife, as exhibited in the figure, became spasmodically convulsed on the occurrence of every spark that passed from the electric machine.*

Figure 10.



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* In the early history of the physical sciences the professors were less sumptuously provided with ample appliances of apparatus than at the present day. It was customary for them to reside with their families in the lecture-rooms. So late as the year 1825, I visited the rooms of an aged professor of anatomy, at Amsterdam, in Holland. I found him with his wife and a domestic occupying the apartments containing the glass cases and ranges of tables filled with anatomical specimens, and surrounded by animal monstrosities, preserved in spirits in glass jars. His wife was seated familiarly by the side of a white-ribbed skeleton, busily engaged in shelling peas. The domestic was employed in kindling a peat fire beneath the dinner-pot, suspended in the great fire-place of the principal exhibition room.

Restricted pecuniary means in former times thus once brought "science and the useful arts" into close communion together. It was doubtlessly to this fortunate

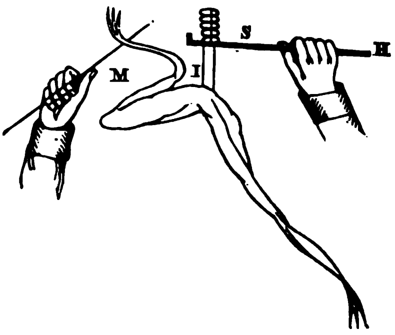
The phenomena of the spasmodic convulsions of the frog's legs were described by Mrs. Galvani to her husband, who instituted a course of experiments to verify them.

He found that the electric sparks from the machine did not pass directly to the blade of the knife, and to the electro-scopic nerve of the frog's legs; and consequently, that it must have induced a disturbance of the electric matter naturally existing in a state of rest in connection with the metal. This mode of inducing electric excitation in one body by a disturbance of electric excitation in an adjacent one, has been denoted by the term INDUCTIVE EXCITATION.

On subsequently hanging the legs by a copper hook on an iron railing, he noticed that similar convulsions ensued on contact with the metals.

By repeating the experiment of the contact of different metals, another experimenter, Volta, was led to affirm that the electric excitation in the preceding case, was due to *the contact of two metals.*

Fig. 11.



Subsequent experimenters have demonstrated that the mere contact of the toe of the frog with a portion of the spinal nerve, laid bare for the purpose, as exhibited in the figure, was sufficient to induce muscular contractions without the necessity of using metals at all; a glass rod S, being used to raise up the end of the bare spinal nerve I, and another similar rod M, being used to lift the leg.

Galvani considered that the exterior muscles and interior

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association that mankind are indebted for the original discovery of one of the most important facts of modern science.

In the description of the preceding domestic scene, I should not, however, omit to state, as an ameliorating circumstance, that the appearance of the skeleton standing by the side of the chair occupied by the professor's wife, was rendered somewhat less repulsive, as a member of the family circle, by covering his bald, white skull with a cast-off bonnet, decorated with blue ribbons.

nerves represented the opposite coatings of the exterior and interior of a Leyden jar; and that an electric discharge takes place, as occurs between the interior and exterior coatings.

He supposed that when a volition willed to move a limb, the nerves, aided by the brain, drew forth a discharge from the interior of the muscle to the surface of it.

In examining the history of Volta's early experiments, it appears that his attention was first devoted to the subject of electrical excitation by the contact of metals placed above and beneath the tongue in the mouth. More than twenty years before Galvani's discovery of the electroscopic twitchings of frogs' legs, as above narrated, Sultzer wrote a treatise on the "Theory of Pleasures," wherein he noticed a remarkable sensation of *tasting*, "similar to that of vitriol of iron," produced by placing a piece of silver coin above the tongue, and a piece of copper coin beneath it, and by bringing the edges of the metals into contact with each other.

This experiment continued to be repeated frequently by philosophical experimentalists, as verifying a very singular fact; but without further special notice. More than thirty years afterwards, Galvani's startling discovery of the muscular contractions of frogs' legs produced by the sparks from an electrical machine, and by contact with metallic hooks, on which the legs were afterwards suspended, served to awaken renewed attention to the experiment described by Sultzer.

Crêve and Fabroni, in reasoning upon the experiment of Sultzer, displayed extraordinary sagacity for that early day, by ascribing the exciting cause of the action on the tongue to a *chemical* cause.

After repeating Sultzer's experiment of the application of a piece of metal above the tongue, and of another kind of metal beneath it, Volta stated in a letter to Cavallo, (published in the Philosophical Transactions in 1793,) that he purposely placed himself before a looking-glass, to see if his tongue *trembled* when the contact was made. He confesses he felt "a very unexpected sensation, but the expected motions did not take place."

Volta now commenced experimenting, to prove the truth of his preconceived theory, that the electric excitation originated from the contact of the two metals.

Being aware that this experiment of Sultzer did not admit of exhibiting increased intensity of excitation without increasing the number of coins placed above and beneath several tongues, and that to increase the number of tongues would require the cumbrous appendage of a man at the end of each tongue, he devised the expedient of substituting, in place of the tongues, a multiplied series of pieces of cloth wet with salt water, so as to resemble as nearly as possible the condition of the human tongue whilst naturally moistened with saline saliva. He arranged the pieces of the two kinds of metals alternately above and below the moistened pieces of cloth, in the same order as in the experiment on his tongue, thus forming a considerable *pile* of these alternated series, capable of producing a correspondingly more intense electric action and spasmodic trembling of his tongue, as well as a more acrid taste.

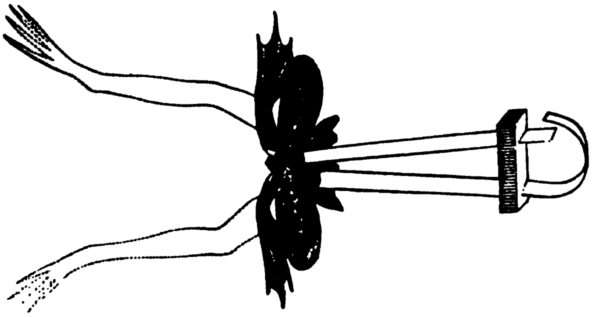
This *pile* was the rudimentary origin of an entirely new mode of developing electric excitation, without recourse to mechanical friction, as had always previously been necessary. The massive pyramids of Egypt, designed to perpetuate the names of kings, may pass away ere the memory of the construction of this little "VOLTAIC PILE" will be obliterated from the annals of science.

This brilliant discovery has led philosophers enthusiastically to denominate this new mode of electric excitation without recourse to electrical machines, by the name of "Voltaic Electricity." But if it be considered, that the recoil of the atoms of both organic formations of food burnt in animal bodies, and of zinc and other metals decomposed in battery cells, from their respective constrained static conditions of groupings to their natural static conditions of groupings, be similar in result, it would be doing injustice to the memory of Galvani, to suffer his name to be thus supplanted.

The fact of the extremely delicate electroscopic sensitiveness of animal nerves and muscles, as first noticed by Galvani, in bringing the parts of the frogs' legs into contact with the copper hook and iron railing, admits of being palpably illustrated by the experiment exhibited in the annexed figure.

The principal nerve of the vertebræ or spinal cord of a frog is laid bare to receive the contact of the two different kinds of metal. The legs being drawn up in a contracted position, at the instant the elastic, arched end of one of the pieces of metal is brought into contact with the other piece of metal by pressing it down with the finger, they become thrown out and extended, as denoted by the dotted lines shown in the figure.

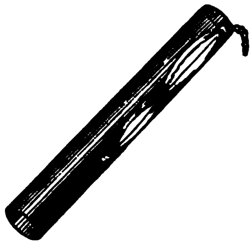
Fig. 12.



In experimenting upon the comparative susceptibility to excitation of various instruments by slight causes of electric disturbances, Dr. Wilkinson states, that two pieces of zinc and silver, each presenting a superficial surface of only $\frac{1}{10}$ inch, produced violent contractions of the muscles of a frog's leg, whilst it was necessary to bring two large circular plates of zinc and copper twenty times in contact with a condenser, before any sensible divergency of the gold leaves of an artificial electroscope were discoverable. Hence he calculated the difference of the relative superficial surfaces of the two plates, multiplied by the number of contacts, as a proof that the susceptibility of muscles to propagate electro-dynamic action in the modified form of muscular contractions and animal motive-power, to be 56,000 times greater than that of the most sensitive condensing electroscope!

Availing himself of this fact, Professor Matteucci made a regular frog-galvaniscope, by skinning the leg, and leaving attached thereto as much as possible of the spinal nerve, on separating it from the trunk. The leg he then placed in a glass tube, with the exposed end of the nerve hanging over the edge, as shown in the figure. By bringing this nerve into contact at once with the two lips of a deep incision made in the muscles of a recently amputated human limb, a contraction of the frog's leg instantaneously ensued.

Fig. 13.



By means of this instrument, the direction of the current, as well as its power, is detected. The professor found, that the frog-galvaniscope will contract on *making contact* with the body to be tested, if the current pass from the nerve to the leg; whilst the same contraction will occur on *breaking contact*, if the electricity be moving in the opposite direction.

From the use of this instrument, Matteucci affirms, that the intensity of electric currents rises in a ratio corresponding with the rank occupied by the animal in the scale of being, and that the continuations of the currents after death are in an inverse ratio. He further noticed, that if the cause of death of an animal be such as more thoroughly to counteract the *vis vitæ*, as by asphyxia from immersion in hydrogen gas, the appearance of electric action is more suddenly suspended after death.

The preceding facts demonstrate, that animal nerves and muscles truly constitute real electroscopic mechanisms of a most delicately sensitive character. Were they not carefully covered up within the interior of the body, every contact with metals and other substances, and every change of temperature, would induce spasmodic muscular contractions and convulsive twitchings of the limbs. The fact of the sensitiveness of the bared nerve of a tooth is too familiarly known to require describing.

Whenever these involuntary spasmodic twitchings and shocks are experienced by living intelligent beings, producing an action and sensation so different from that producible by any other known cause, they hesitate not to ascribe them to "electricity," as a cause of this peculiar propagation of mechanical action. Even a dog of the Newfoundland species, after having his back subjected to friction with a warm silk handkerchief to produce electrical excitation, and after experiencing the shock of a spark drawn from the nervously sensitive end of his nose, appeared perfectly to comprehend the effects of the propagation of electro-dynamic action; and in anticipation of it, I have known him to leave his place by the fireside, and retreat with a growl significant of displeasure, when a silk handkerchief was approached toward his back.

An earthworm, or garden-snail, when placed on a piece of copper lying on a plate of zinc, will recoil as often as he touches the zinc in attempting to leave the copper, his nerves of sensation being affected by the propagation of the electro-dynamic action, whenever his body constitutes a portion of the circuit. Thus it appears that the nerves of all animals are exquisitely sensitive to the slightest disturbances of the universally diffused electric matter.

These spasmodic muscular contractions, producible by the propagation of electro-dynamic action, are not accomplished feebly; but on the contrary, with a powerful development of impulses of mechanical force. Through the mechanisms of nerves and muscles, the electro-motive power becomes propagated in the modified form of animal motive power, as we shall presently have occasion more amply to illustrate, when we come to treat specially of this subject. In anticipation it may be here readily comprehended, that were the motor nerve of the arm of a recently dead human subject to be connected with the wire of an electric telegraph, and were a pencil to be fixed within the clenched grasp of the fingers, at every touch of an operator on the key of the instrument a hundred miles distant, the lifeless hand would inscribe a mark of the pencil on paper, like the recording apparatus of an electro-magnetic telegraph. The will of the manipulator at a distance would thus be enabled, for a short period, to control the movements of the mechanisms of the animal organic formation left deserted by the master spirit that once actuated it.

A convulsive twitch of the lifeless hand might thus also be produced by the occurrence of every flash of lightning in the clouds within several miles of the extended wire.

Having thus briefly traced out the functions of mechanisms o animal muscles and motor nerves as constituting, by their spa modic contractions, the most delicately known standard tests of the slightest disturbance of electric matter, and of the propagation of electro-dynamic action in the modified form of animal motive power, our attention will now be directed to the functions of the antagonistic sensorial nerves. These nerves serve to propagate electro-dynamic action from the objects of the external world as telegraphic signals to the tribunal of human intelligence located in the brain.

NERVES OF SENSATION CONSIDERED AS STANDARD ELECTROSCOPIC TESTS OF PHYSICAL SCIENCE.

The organ of the brain, as has been stated, is divided into five distinct circuits, each provided with two arrangements of nerves denominated the motor, and the sensorial nerves. The propagation of electro-dynamic action through the medium of the former, has just been considered. It remains to trace out the propagation of electro-dynamic action through the medium of the latter to the tribunal of human intelligence.

The electro-dynamic action propagated through the five distinct arrangements of sensorial nerves are recognized as the five distinct senses, or sensations, and are denoted by the distinct appropriate names of *feeling*, *tasting*, *seeing*, *smelling*, and *hearing*.

The impressions produced by the propagation of this electro-dynamic action on the intelligent essence located in the brain, are termed *sensations and perceptions*.

As metaphysical inquiries into the modes of exciting and transmitting ideas do not come within the province of mechanical philosophy, our present investigations will be limited to a few brief illustrations of the propagation of electrical action through the medium of the five distinct material nerves of sensation, as constituting the only standard tests by which human intelligence is enabled to gain knowledge, and to form truthful judgments, of the objects of the external world.

Nerves of Feeling considered as standard tests of Physical Science.

When violent electro-dynamic action is propagated through the motor nerves of the muscles, to produce spasmodic muscular contractions, these violent contractions affect the sensorial nerves, inducing a propagation of electro dynamic action in an opposite direction toward the brain, recognized as *feelings*, or sensations of pain. These electro-telegraphic communications to the organ of the brain through the nerves of feeling, considered as standard tests of physical science, are adjudged by the tribunal of human intelligence to be perceptions of *electricity.*

"A single pair of small plates of zinc and copper, only one or two inches square, immersed in acid, will furnish sufficient electricity to render *red hot* one inch in length of a platinum wire of the diameter of $\frac{1}{100}$th part of an inch," as stated by Mr. Snow Harris.

At the commencement of the propagation of the electro-dynamic action through this wire, whilst lightly grasped between the fingers, the vibrations of the atoms of the wire first impart to the nerves of the fingers a mechanical action, which is recognizable as a sensation of *warmth*, then of a burning *heat.* The cause of this sensation, although manifestly electrical, being ascribed also to another agency, popularly denominated "Heat," or "Caloric," there are thus assigned two distinct causes for the same effect,—a result unknown in the economy of nature; two causes never having yet been discovered to be adapted to producing identical effects.

Whenever the nerves propagate the sensation of a burning heat, the intensity of the Inorganic reaction overpowers the Organic action, which sustains the grouping of the atoms of the four organic elements in the constrained static condition of the material nerves of the body; and they begin to yield to the now paramount power of this Inorganic reaction, and to become resolved into their natural static condition of carbonic acid gas and water. The excessive intensity of the propagation of the electro-dynamic action now induces the more intense action recognizable by the tribunal of human intelligence, as a sensation o *pain*, which, as before stated, is thus manifestly a salutary signa warning, benevolently designed for preserving unimpaired the means of communication between mind, and the matter of the external world.

These facts also demonstrate the necessity for the employment of another class of nerves,—those of the eye, as a milder and safer mode of electroscopic communication at a distance with bodies intensely excited by electrical action.

The various phenomena of "heat," as judged by the electroscopic tests of the material nerves of the body, and also by the test of a dynamic action on lifeless inorganic matter, will presently occupy our attention as a branch of electrical science, denominated "THERMO-ELECTRICITY;" the term "Thermo" being derived from a Greek word signifying *heat.*

The preceding illustrations are designed simply to demonstrate, that the material nerves of feeling constitute electroscopic mechanisms, and to prepare the mind of the reader for the reception of further truths of the identity of the phenomena ascribed to the action of "*heat,*" and of "*electricity.*"

The material Nerves of the Eye considered as standard electroscopic tests of Physical Science.

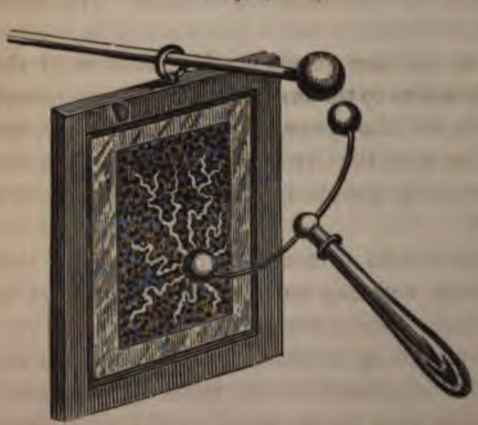
The mechanism of the nerves of the eye are skilfully contrived to subserve the purpose of enabling the tribunal of intelligence to hold communication, without injury, even with red-hot metal, as described in the preceding experiment. When the propagation of the electro-dynamic action has become so intense through the wire, as to produce mechanical vibrations of the particles, which are destructive to the organic texture of the nerves of feeling in the fingers, or other parts of the animal body, another set of nerves,—those of the eye, are brought into requisition. This extreme action is popularly recognized as that of a "red" or "white heat."

Were human beings devoid of sensitive nerves of the eye, like the blind fish found existing in the Mammoth Cave of Kentucky, the increment of temperature of the piece of conducting wire, in the preceding experiment, would unhesitatingly be ascribed to an increment of the intensity of electro-dynamic action. In this case there never would have been imagined to exist such an imponderable agent as that now popularly denominated "Light."

Where there is no excitation of the optic nerves by the electro-dynamic action in the modified form of light, there the animal mechanisms are found to be actually devoid of the electroscopic organs of the eye. In the specimens of a fish, and a species of crawfish, which I obtained in Kentucky, from the celebrated Mammoth Cave, where the electro-dynamic action of the sun never penetrates, there are actually no formations of the organs of eyes. In the admirable economy of nature, the means are thus ever found to be adapted to the ends to be accomplished. Where the propagation of the electro-dynamic action of the sun in the modified form of light is wanting, long slender *antennæ*, or *feelers*, serve as a substitute for eyesight. Doubtlessly the nerves of smelling are more exquisitely sensitive in these naturally blind races of animals, than in any other class of animated beings, to enable them to procure their appropriate food.

The phenomena of Light, developed by direct propagation of electro-dynamic action upon the material nerves of the eyes of animals, is familiarly known and recognized in the vivid flashes of lightning, which for an instant throw the effulgence of a mid-day sun over a landscape during a thunder-storm at midnight. The perception of electric sparks are also familiarly shown by various kinds of electric apparatus, common in the lecture-room. Plates or tubes of glass are employed for this purpose, coated with small patches of metals reduced to their leaves, leaving frequent intervals for the sparks to leap over, as shown in the figure.

Fig. 14.



The electric light is most beautifully exhibited in the void space of the bell-glass of an air-pump, as shown at page 60. The flashes appear darting about within the glass for a long time after the original exciting cause has been withdrawn, continuing to propagate electro-dynamic action to the nerves of the eye recognizable in various grades of intensity, representing *colors* of various hues, of purple, scarlet, &c.

That the nerves of the eye are really most sensitive, electroscopic tests of the slightest propagation of electro-dynamic action is experimentally demonstrable, by the same experiment of placing pieces of metal above and beneath the tongue, which was resorted to by Volta, as before described. On bringing the edges of the plates into contact, a vivid flash of light becomes perceptible, with the eyelids closed, and in a dark room. A similar appearance of light may be perceived by persons wearing a plate of gold in the roof of the mouth to sustain artificial teeth, whenever the blade of a steel knife which has been employed in cutting acid fruit, is brought in contact therewith.

Thus, the feeblest excitation of electricity is sufficient to act upon the delicately sensible nerves of the eye, as upon a most exquisitely sensitive electroscopic apparatus.

But when a powerful galvanic battery is employed purposely to develope the phenomenon of light, as is effected by causing the current to pass an interval of space between two charcoal points, the electro-mechanical action produces sensations of the most vivid light,—rivalling that of the splendor of the meridian sun, and overpowering, painfully, the contracting nervous tissues of the eye.

When the two charcoal points are separated a short distance, the intervening space becomes occupied by a dazzlingly brilliant flame, of which the "light and heat are the most intense that art can produce," as stated by Dr. Hare. He narrates, that "on one occasion, after making some experiment, with an extensive series, 'my eyes were so much affected, that all other flame appeared of a deep blood-red; and on the following day they were bloodshot, and so greatly inflamed, that it was deemed expedient to apply twenty leeches to each to procure relief."

Percussion, friction, and every other kind of mechanical action, induces disturbances of the electric matter existing in connection with the bodies thus acted upon. It is experimentally found that a sudden blow or percussion, developes flashes in various hard bodies, when struck violently together, as when two stones, or other substances, are brought into collision. So also, when a blow is struck upon the head, this cause of electric disturbance induces a flash of light in the electroscopic organ of the eye. The rubbing of the eye, or the pressure of the eyeball, and even the action of a violent dry wind, will similarly induce disturbance of the electro-static condition of the nerves of the eye; for it is only whilst the net-work of the nerves constituting the retina of the eye remains unexcited, or in a perfect electro-static condition, that the peculiar absence of all excitation exists, which is recognized by the tribunal of intelligence as "DARKNESS."

Indeed, were not the exceedingly sensitive optic nerves carefully withdrawn within the bony case of the skull, and screened by a self-closing curtain, which is electro-dynamically self-regulated in expanding and contracting, in accordance with the intensity of the excitation to which it may be exposed, the slightest movement of the ever-ebbing and flowing electric currents would produce a continuous and annoying irritability. They would prove a source of pain, instead of producing all the delights of vision.

That there is a sufficient quantity of electricity naturally existing in connection with the crystalline humors and solid matter of the retina of the eye, to admit of developing electrical excitation, is manifest, if Professor Faraday's assertion be true, that a quantity of electricity, equal to that composing a flash of lightning, is developed in connection with the decomposition of a single grain of water.

The supposition that the sensations of light and of colors are the effects of the mechanical disturbance of the electro-static condition of the material nerves of the eye, appears to have been practically known to Newton, as manifested by the experiment which he suggested in the 3d Book of Optics, quere 16. "When a man in the dark presses either corner of his eye with his finger, and turns his eye away from his finger, he will see a circle of colors like those in the feathers of a peacock's tail. If the eye and the finger remain quiet, these colors vanish in a second of time; but if the finger be moved with a quavering motion, they appear again."

Indeed, whatever cause produces the excitation of electricity, will also produce the action on the nerves of the eye recognizable as a sensation, or perception of light. The movement of a magnet near a conducting wire connected with a corner of the eye, produces the sensation of a vivid flash of light.

The electrical eel, in exciting an electrical spark, has command at his pleasure of acting on the electroscopic nerves of the eyes of animals, to induce therein an excitation recognized as an electric spark, and also as a flash of light. It cannot be a matter of surprise, then, that fire-flies and glow-worms are endowed with corresponding control of exciting, at their pleasure, an electro-dynamic action on the nerves of the eye. To those who behold the expanse of a meadow in a dark evening, it appears sprinkled with twinkling lights, as if reflecting, like a mirror, the lights of the stars in the expanse of the firmament above it.

This voluntary propagation of electro-dynamic action by electrical fishes, will presently occupy our attention.

When the electro-dynamic action is propagated by a general equable diffusion over the whole body of an animal, as when a person stands on a stool insulated by glass legs, the electric matter speedily attains a state of equilibrium. The nerves are not affected thereby, until the electric matter becomes disturbed and resolved into a dynamic condition.

It is very remarkable that the sensation of "light," producible by electricity, should have never been popularly ascribed to electro-dynamic action; but always to a distinct and mystified agency, or cause of action.

The preceding facts demonstrate that the action of an electro-current, transmitted through the material particles of a piece of fine wire, is popularly denoted by three distinctive names of "*heat*," of "*light*," and of "*electricity*," according as the electro-mechanical action is exerted upon the material organization of the nerves of the hand, or of *feeling*, of the eye, or of *seeing*, and of the *motor nerves* of the muscles, producing muscular contraction, and consequent animal motive power.

Nerves of the Tongue, or of Tasting, considered as Electroscopic Tests.

The nerves of the tongue are also exceedingly delicate electroscopic tests of very feeble electric action. Indeed, it appears to be attributable to this delicate susceptibility of the nerves of the tongue, that mankind are indebted for the first discovery of the excitation of currents of electricity from the decomposition of metals, as has been recapitulated of Volta's early experiments.

The electro-dynamic action of the two poles of a galvanic battery, applied to the nerves of the tongue, produces not only a thrilling sensation, and spasmodic contraction of the muscles of the tongue, but also the peculiar perception of an *acid* or *alkaline* taste; accordingly as the one or the other pole of the battery is brought into contact with the tip of the tongue in closing the circuit, whilst the opposite pole is held in the moistened hand.

The extraordinary stimulating and pungent sensation, felt at the instant when metallic vessels containing fermented liquors, such as beer, cider, &c., are brought into contact with the lips and tongue, appears to have been practically known, from the fact of the decided preference given to the use of pewter mugs by those who systematically quaff these beverages at porter-houses.

The similarity of the groupings of atoms of numerous kinds of substances producing, by their contact with the tongue, a similar perception of a *sweet taste*, has led Professor Horsford to make the inquiry, "is this similar taste of different substances dependent on this similar arrangement of their minutest particles?[*] After pursuing an elaborate course of analyses of different kinds of compound substances, he further suggests, "may there be a common form among bodies having a common taste?" These suggestions are in perfect accordance with the system we are now engaged in tracing out; for considering all groupings of atoms into visible magnitudes to be mechanical effects produced and continuously sustained by the propagation of electro-dynamic action, we may regard the material nerves of the tongue simply as electroscopic tests specially adapted for recognizing this action, as a perception of a *sweet* taste. If there be not a specific common form of grouping of atoms of all substances having a common taste, as suggested by Professor Horsford, there must certainly be a specific common form of the propagation of electro-dynamic action to the nerves of the tongue, to produce the conformable effects of a sweet taste, as above stated.

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[*] Proceedings of the American Association for the advancement of Science, Fourth Meeting, page 216."

That the nerves of the tongue are relied upon as a standard test of the opposite excitations producible by acids and alkalies, and, indeed, by almost every kind of substance, is manifest from the universal use of the tongue in tasting.

Nerves of the Nose, or of Smell, considered as Electroscopic Tests of the propagation of Electro-dynamic Action.

The extremely electro-positive and electro-negative chemical compounds of acids and alkalies produce also the most powerful action on the material nerves of smelling.

In treating of the development of vegetable organic formations produced by the electro-dynamic action of the sun, reference has been had to the appearance of blossoms during the intense excitation accompanying the fecundation of the germs in the vernal season. It is particularly at this season of the year that the most powerful action on the nerves of smelling is produced, when the whole atmosphere becomes redolent with the perfumes of blossoms.

The keenness of scent in brute animals far exceeds that of man, the tissues of nerves adapted for this purpose being more largely developed in those animals, whose preservation depends on the quickness of their holding electro-telegraphic communications with distant objects.

There is a peculiar odor attending the presence of electricity excited by common friction of electrical machines, which has recently attracted particular notice.

The odor was described many years ago by Mr. Crosse, in experimenting with electricity conducted into his study by a wire extended several thousand feet horizontally upon the tops of poles, as telegraphic wires are now supported. By causing the dense sparks to pass between two metallic plates inclosed in a cylinder of glass, the atmosphere of the interior of the cylinder became so strongly impregnated with a powerful pungent phosphoric odor, that "I found it exceedingly inconvenient to respire over it; nor could I find any individual able to endure its approach toward his nostrils beyond a second or two." This remarkable action on the material nerves of the nose has been denominated OZONE, from the original Greek word OZO, signifying "*to yield odor.*" The odor appears to originate immediately from the action of electric sparks in exciting the atoms of oxygen and hydrogen floating in the atmosphere, which, in this peculiar state, propagate electro-dynamic action to the nerves of the nose, and produce irritation of the mucous membrane of the respiratory organs. A similar electro-dynamic action may be produced by means of the excitation propagated from phosphorus, whilst slowly decomposing in a tube containing moist air.

Nerves of the Ear, or of Hearing, considered as Electroscopic Tests.

The material nerves of the ear are designed to be acted upon mechanically; but not by the vibratory impulses of electric matter, such as affect the material nerves of the eye. Another fluid medium, the air, instead of electric matter, is the intermediate agency adapted for propagating impulses to the vibrating nerves connected with the tympanum of the ear. These nerves are as exquisitely discriminative of the most delicate gradations of intensity of mechanical action thus propagated, and recognizable in harmoniously blended *musical sounds*, as the vibratory nerves of the eye are found to be, from the impulses propagated by the vibrations of the more subtile electric matter, and recognizable as the blended rainbow hues of the prismatic colors.

There remains to be noticed the function of still another organic mechanism, in addition to those of the "five senses," which has not been duly noticed. It is somewhat analogous to that of smelling, as it is susceptible of being very effectively acted upon by electro-dynamic impulses propagated throughout the atmospheric air. The functions of the nerves of the glottis and adjacent membranes of the throat are strictly confined to those of a conservative character, designed to preserve the safety of the lungs, not only from solid impediments obstructing respiration, but also from pernicious aeriform gases, a single inhalation of which might forever incapacitate them for further use, and consequently prove fatal.

To enable these membranes to perform their functions with instantaneous promptness and unerring fidelity, they are specifically endued with a discriminative sensitiveness of their own, independent of the animal volitions, and animal intelligence. They really constitute a self-acting electroscopic apparatus. The energy with which their functions are performed, are familiarly experienced in the sensation of choking, which results from every attempt to breathe the deleterious acid gases of the smoke of burning wood, sulphurous gas, &c. At the distance of more than a quarter of a mile from a laboratory for the manufacture of sulphuric acid, where the process was wastefully accomplished, the escaping gas I have found to propagate electro-dynamic action to this membrane. Involuntary contractions of the epiglottis have warned me of the presence of this pernicious gas in the atmosphere, when the inferior susceptibility of the nerves of smell afforded no indication of the fact.

This necessarily brief recapitulation completes the notice of all the several standard tests, which intelligent sentient beings are unavoidably under the necessity of employing as their sole available means of gaining a knowledge of the conditions of the matter of the external world. The knowledge thus gained by these several electroscopic standard tests constitutes physical science. The importance of duly comprehending the nature of them, as they are employed to determine the truths of physical science, although hitherto overlooked, is manifest from the preceding analysis; for, on a just appreciation of them, must depend the truthfulness of the conclusions determined thereby.

Conclusions deduced from the use of the preceding Tests of Electro-dynamic Action.

The preceding examination of the nature of the tests relied upon by human beings for gaining intelligence of the objects of the external world, is of essential importance, as constituting the basis of all investigations into the physical sciences.

Sufficient details have been adduced to demonstrate that all the groupings of atoms of the four organic elements into the organic formations of the mechanisms of the nerves of animal bodies, are specifically designed to modify the propagation of the electro-dynamic action, and to subserve the practical purposes of electro-telegraphic instruments for systematically communicating comprehensible signals from the objects of the external world to the immaterial essence of intelligence embodied therein;—from matter to mind, and from mind to matter. It has been shown that one cause alone, electro-mechanical action, in the variously modified forms of Organic and of Inorganic action and reaction, is adequate to produce all these specific effects of sensations of heat, of light, and of electricity. In the simple and beautifully systematic operations of natural causes, two or more distinct agencies are never found to be employed for producing identical effects. Consequently we are led to judge by the preceding standard tests of the *five human senses*, or faculties of perceptions, that there is really only one identical cause of all the phenomena popularly ascribed to three distinct imponderable agents—heat, light, and electricity.

In treating of this subject, Professor Whewell has observed, "we have strong reasons to believe that *light* is not matter, but only motion; and that the same thing appears to be probable in regard to *heat.* Light and heat are not things," &c. Instead of considering heat and light to be "only motion," they may rather be deemed to represent the modified propagation of impulses of mechanical action through the medium of electric matter, as will be presently more particularly demonstrated.

A brief view has now been taken of the functions of the material nerves of the mechanisms of animal organic formations considered as natural telegraphic instruments, designed to propagate electro-dynamic action between the immaterial essence of the mind—the tribunal of human intelligence—and the objects of the external world.

It remains to investigate the facts of the electro-dynamic action developed between lifeless matter similarly employed as standard Electroscopic Tests of the propagation of electro-dynamic action.

ARTIFICIAL ELECTROSCOPES AND GALVANOSCOPES CONSIDERED AS STANDARD TESTS OF PHYSICAL SCIENCE.

The movements of atoms and of masses of matter constitute the basis of the operation of all kinds of electroscopic instruments.

The mechanical movements of matter originally led to the discovery of electricity, as first noticed in the apparently self-actuated approach of straws, feathers, and of other similar light bodies, toward pieces of amber which had been subjected to friction. This first and earliest test of electrical excitation—the movement of matter—still continues to be the principal standard test of electrical excitation.

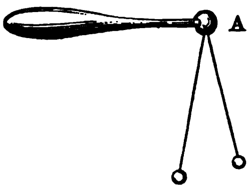
In the previous pages, it has been shown in treating of the *static* conditions of groupings of atoms into inorganic and organic formations, that to produce the phenomenon of their relative state of rest in fixed positions of solid bodies, there must be counterbalanced action and reaction of impulses of mechanical force. It must appear equally manifest, that to produce the movements of matter, there must be a disturbance of this counterbalanced condition of oppositely directed impulses of action and reaction. Although the movement of one solid body near another may not produce any disturbance of the relative fixed positions of the solid groupings of such atoms, yet every experiment of the movement of one body near another has been found to induce disturbances of the relative state of rest of the more freely movable electric matter existing in connection therewith, and the consequent development of impulses of mechanical force, propagated through the medium of this disturbed electric matter.

As the atoms of electric matter, like all other elementary atoms, are too minute to be directly discoverable, and as they cannot be collected or condensed into discoverable liquid, solid or ponderable aggregations, it appears to follow as a natural consequence, that it must be in vain to hope for the discovery of any standard test of the presence of electric matter in motion, or in an excited state, other than that of its propagation of motion to some kind of freely movable and palpable portions of matter.

Such portions of matter when arranged into the form of instruments for receiving and propagating the electro-dynamic impulses, have received the names of *electroscopes*, from the Greek word ELECTRON, signifying *amber*, figuratively applied to denote *electricity*, and from another Greek word, SKOPEO, *I behold:* the view of the movements producible by electrical action being assumed to be equivalent to the view of the electric matter itself.

In the construction of all kinds of electroscopes, the principal study has been to arrange the lightest, or most flexible portions of matter, in the most freely movable positions near each other. Although feathers, pieces of threads, and of straws, may serve to detect by their movements the propagation of electric action, yet convenience has been consulted in using other substances systematically arranged in the form of instruments.

Fig. 13.



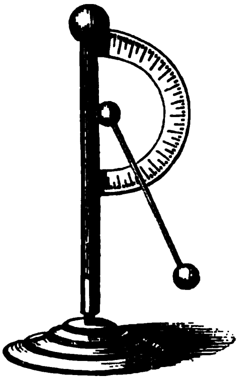
One of the simplest kinds of electroscopic instruments is constructed of a couple of balls of the size of a pea, made of the pith of alder or of a corn-stalk, suspended by very fine silver wires, or threads coated with black lead, and suspended from a metallic knob A, attached to a glass handle to insulate it, as shown in the figure.

On bringing the knob A into contact with an excited body, the balls will become divergent as seen in the figure; and if a body be not electrically excited, the balls will continue drooping in contact with each other.

The different degrees or extent of their divergency will of course indicate the degree of intensity of the electro-dynamic action. This fact of a reciprocal separation or repulsion of two bodies, is assumed to be a test of electric excitation.

A graduated electrometer is exhibited in fig. 14, which is well adapted to indicate the intensity of the electro-dynamic action.

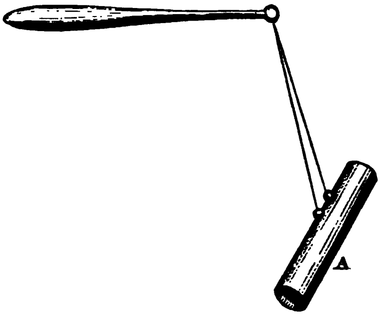
Fig. 14.



The pith ball A is attached to the end of a very slender fibre of light wood, having a movable joint by means of which the pith ball has freedom of motion to rise and fall, accordingly as the increasing or subsiding intensity of the electro-dynamic action may affect it in its natural drooping position. The graduated semicircle serves to indicate, by the degrees marked thereon, the exact comparative extent of the force of the electrical action imparted from the differently excited bodies upon which it may be placed.

But the most ready way to test the primary effects of the electro-dynamic impulses exerted by excited bodies, is simply to hold the pair of insulated balls near them. If A represent a piece of amber, glass, sealing-wax, &c., previously excited by having been rubbed by a dry, warm cloth, it will be found that the balls will become first urged toward the rubbed body A, as shown in the figure.

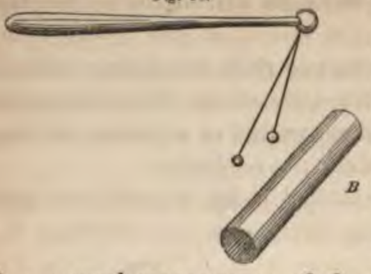
Fig. 15.



After remaining in contact therewith for a moment, the two balls will be found to be urged therefrom, as shown in figure 16. The two balls will also be urged reciprocally from each other.

Otto Gueriche appears to have been the first writer, who noticed the fact that after a body has received excitation by contact with an excited body, and has been repelled therefrom, it remains incapable of a second attraction until after it has propagated the electro-dynamic action to some other conducting body, toward which it will become urged. This fact is a natural consequence of the universal law of mechanical action and reaction between bodies; for in the preceding figure the excited body A must be urged toward the adjacent pair of pith balls with precisely the same force that the pith balls are urged toward A. And for the same reason the pith balls, excited by contact therewith, and receiving the propagation of the electro-dynamic action, must similarly attract, and be attracted by, adjacent unexcited bodies.

Fig. 16.



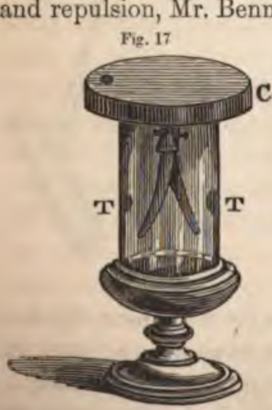
From the preceding electroscopic tests, the following law of electro-dynamic science has been established.

An unexcited and an excited body are reciprocally urged toward each other by electro-dynamic action.

Two bodies receiving the propagation of electro-dynamic action from the same source, are found to become reciprocally urged from each other.

Taking advantage of these two combined forces of attraction and repulsion, Mr. Bennet contributed an improved electroscope, in which he substituted, in place of pith balls, two narrow strips of flexible gold leaf, as exhibited at A in the figure, the lower ends of the gold leaves being arranged opposite to two strips of metallic leaf, T T, pasted upon the inner side of the glass tube and connected with other conducting unexcited bodies. The glass tube is used to insulate the cap, and to prevent disturbance of the leaves by currents of air. By this arrangement, when the metal-

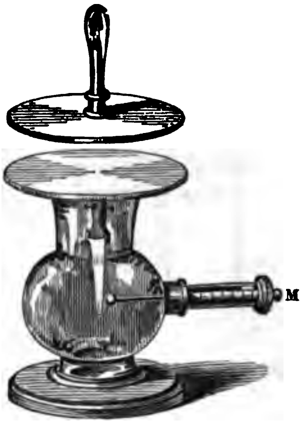
Fig. 17



lic cap or cover, C, from which the leaves are suspended, is touched by an excited body, the leaves are urged to become separated by a double intensity of electro-motive power,—the attraction between the gold leaves and the two strips of metal opposite them being superadded to the reciprocal repulsion between the two leaves. Thus a slight degree of excitation is rendered manifest by this arrangement.

Hare's Electroscope.—A still further improvement on this instrument has been made by Dr. Hare, by inserting a wire, M, with a brass knob affixed to the end of it, which may be approximated by means of a screw cut upon its circumference to within a very minute distance of a single strip of gold leaf. The intensity of the propagation of the electro-dynamic action through a space of air being found to decrease in the inverse ratio of the squares of the increased distances, this instrument becomes thus exceedingly sensitive to the slightest disturbances of electrical matter in the gold leaves propagated from the metallic cap, which is made of zinc.

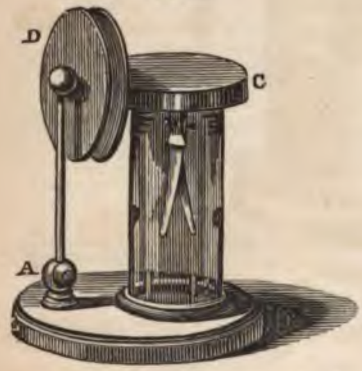
Fig. 18.



By means of this simple instrument, one of the most important facts in the whole science of electro-dynamics may be experimentally demonstrated by bringing into contact with the plate various kinds of metals, as the plate insulated by a glass handle. A disturbance of the natural electro-static condition of the plate and of the gold leaves suspended therefrom, is producible by the simple approximation and contact of various bodies with the plate; the sifting of various pulverized substances thereon being sufficient to produce the movement of the gold leaf. Both of these metallic plates may be separately examined by the test of the contact with other electroscopes composed of pith balls or flexible gold leaves, and no signs of electricity will be discoverable. Now place the plate of copper, on the plate of zinc, which is called the *cap of the electroscope*, and hold one hand in contact with M, which is to be screwed up until the ball at the end of it is brought close to the tip end of the pendent strip of gold leaf; and with the other hand, touch the copper plate, and then lift it by the glass handle from the zinc. At the instant the separation is effected, the gold leaf will be seen to strike the ball, if the latter be previously brought to within the distance of $\frac{1}{20}$th of an inch from the former. This instrument serves the purpose of a delicate *electrometer* to measure very minute degrees of intensities of electrical action.

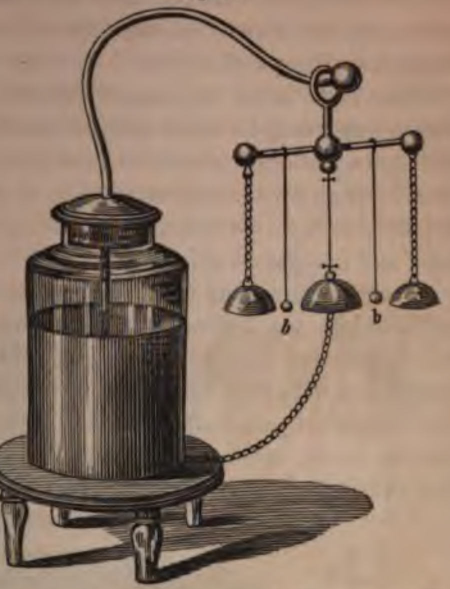
Volta's Condensing Electroscope.—It has been experimentally proved by the preceding experiment with Hare's electroscope, that the contact of one metal with another causes excitation of electrical forces. This fact was early discovered by the genius of Volta. It is found, that as the actual contact of two metals will produce this result, the sensitiveness of the gold leaf electroscope of Bennet may be much increased by the addition of two metallic plates or disks as shown at D, one of which is soldered to the cap, C, and the other attached to the foot of the instrument by a metallic rod, and movable hinge, A. By this arrangement the plate mounted on the movable hinge may be swung upwards until it is brought as near the other plate as possible, without actually touching it. The strips of tinfoil pasted on the inside of the glass are to be continued, to form a metallic communication with the bottom of the rod or hinge at A.

Fig. 19.



This instrument is used by bringing the different bodies to be tested into contact with the cap, C; and on removing the plate, D, on its hinge, three or four inches from the plate soldered to the cap, the gold leaves will be seen to diverge. By this contrivance the phenomenon of the movements of the passive matter, composing the pendent leaves, is readily producible by the mere contact of various kinds of elementary substances. And when a single contact will not produce this result, let the operation be repeated fifteen or twenty times, and an accumulation of these multiplied additions of electricity will finally produce a sensible divergency of the gold leaves.

Fig. 20.



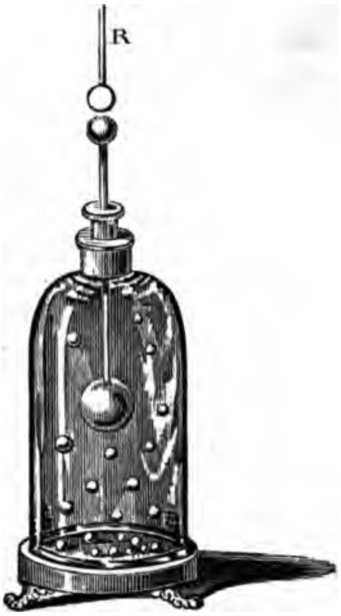
The fact that an unexcited freely movable body is first urged toward an electrically excited body, and after receiving a charge by contact therewith, is then repelled therefrom, admits of a beautiful mode of illustration by means of the familiar experiment of ringing a chime of bells by electrical agency.

In the annexed figure, the two outer bells are represented as being suspended by metal chains attached to the rod appended to the excited conductor of an electrical machine, and they become charged with electricity through the communication afforded by these chains. The two adjacent metal balls and the middle bell are suspended from the same rod; but non-conducting silk strings are used, instead of chains. A chain is attached to the middle bell to furnish a pathway for the propagation of the electro-dynamic action that may be communicated to it, to the coating of the jar. The two outer balls, being electrically excited bodies, are first urged toward the excited metallic bells, instead of motionlessly drooping near them; and at the instant that contact takes place between the balls and the bells, the latter receive the propagation of electrical action from the respective bells against which they strike forcibly, and produce a tinkling sound. On the principle before demonstrated, that two similarly excited bodies become reciprocally repelled, the metal balls are then urged from the bells; whilst at the same instant the unexcited middle bell now stands in the same electric relationship to the excited balls, as these balls were in originally in relation to the outer bells. Consequently the phenomenon of attraction is seen to take place between both balls and the middle bell, and a violent contact ensues between them, thus again producing a continuous ringing of this bell.

The balls, after propagating their electro-dynamic impulse, become restored to their original neutral unexcited condition, and again undergo reiterated repetitions of similar movements, thus keeping up a constant ringing of the bells, so long as there is a difference in the intensity of the electrical excitations in the bells and freely movable balls.

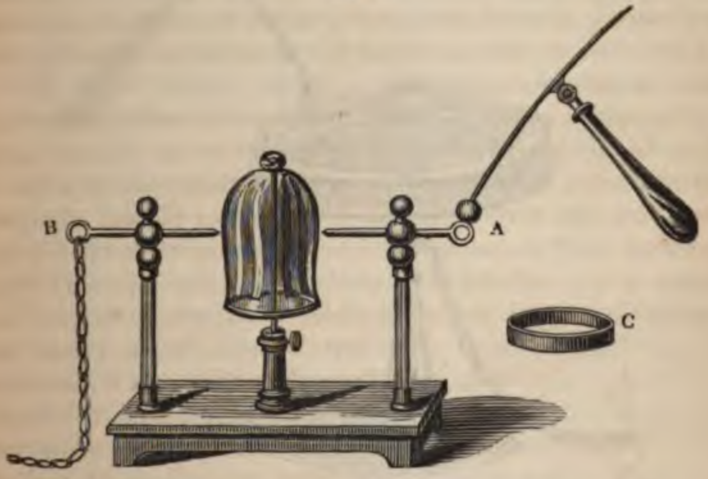
Precisely the same phenomena of attraction and repulsion are exhibited in the following experiment, where an excited brass ball is inserted through the top of a bell-glass, directly above a plate filled with small light pith balls of about the size of a pea. The unexcited pith balls become first urged upwards toward the excited knob, and after contact therewith, they become urged downwards toward the metal plate, which transmits their respective impulses until they become counteracted by the reaction of the electric matter of the earth; after which they are again immediately urged upwards toward the knob, and each of them again urged downwards after contact therewith. This operation is kept up with great rapidity, so long as the difference of electrical excitation is maintained; and so remarkably rapid are the movements of a considerable number of these white pith balls, that they present the appearance of a sort of hail-storm within the cavity of the bell-glass. Hence this experiment has been denominated "*electrical hail.*"

Fig. 21.



The same principle of the development of the electro-motive power may be applied to produce the revolving movements of bodies, and a machine-like operation of mechanism, whereby a large bell-glass may be made to revolve on the pivot of a perpendicular pointed wire, with remarkable rapidity, as shown in the annexed figure; which represents a piece of apparatus, invented by Franklin Peale. A bell-glass is shown, having strips of tinfoil pasted upon its outer surface, mounted on the top of a pointed wire, and arranged between two pointed wires, supported on glass pillars; one wire, A, communicating with the prime conductor of an excited electrical machine, and the other, B, with the rubber of the same machine. The strip of tinfoil pasted on the side of the bell-glass next to the end of the pointed wire connected with the excited conductor, becomes charged with electricity therefrom; and on the principle that repulsion ensues between similarly excited bodies, that portion of the excited bell-glass is urged to move from the pointed wire, A, and is at the same time urged to move toward the unexcited wire, B. And thus the different parts of the surface of this bell-glass are successively urged from the pointed wire, A, toward the opposite pointed wire, B, and a rapidly-revolving movement of the bell-glass ensues.

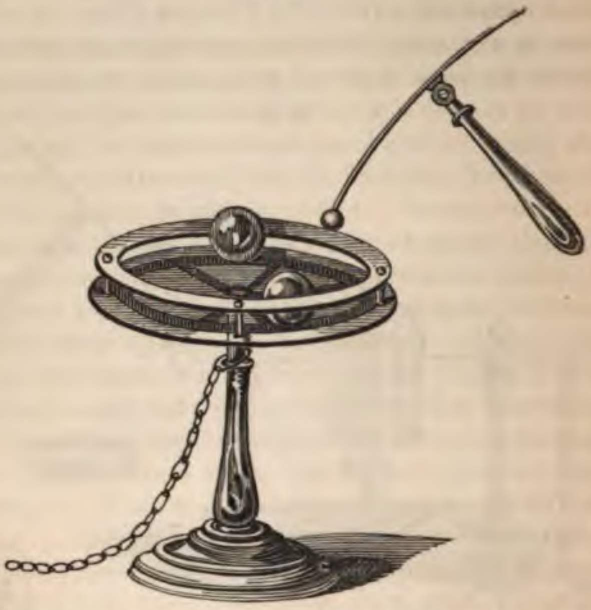
Fig. 22.



By slipping the metallic band, C, over the bell-glass, its conducting power transmits the charge directly from the one pointed wire to the other side without imparting movement to the glass.

If, instead of large globes of glass, smaller ones, of about the size of an orange, be substituted, as shown in the annexed cut, the same principle of electro-motive power will cause them to revolve on a horizontal glass platform around the circuit of the brass railing, with surprising velocity, each ball pursuing and being pursued, as if chasing each other in their rapid flight. In this case, the balls rest upon a circular strip of tinfoil, pasted around a sheet-glass platform, and the brass railing is insulated and connected with the excited electrical machine. The part of the glass bubble that rests immediately against the circular railing, becoming similarly excited, and attracted by the tinfoil beneath it, whereby the bubble is determined to turn over, on being repelled, and to roll forward continually, their centrifugal tendency keeping them in contact with the circular ring of brass.

Fig. 23.



Innumerable other instruments have been ingeniously contrived for exhibiting demonstrative proofs of the propagation of mechanical impulses through the medium of electric matter.

The preceding examples are sufficient to show the practical results of the movements of bodies, caused by electricity, in an apparent state of rest, or statical condition, in connection with insulated bodies, wherein no perceptible currents are observable, such as occur when the electric fluid is caused to flow in palpable currents, or disruptive discharges, through a space of air, or along conducting wires.

There is a remarkable exception to the law, that bodies excited from the same cause of propagation of electro-dynamic action, or by contact with the same excited body, reciprocally repel each other; for it is found that although this law holds good on the instant of contact of the pith balls with the excited body, yet when the contact has been prolonged and rendered more intimate by pressure, that an *attraction*, instead of *repulsion*, takes place; as also occurs when one of the ends of a magnetic needle is brought into contact with the repellant end of a powerful bar magnet. The two poles at first reciprocally repel each other; but if the needle be forcibly held for an instant, with one of its poles in contact with the similar pole of the bar magnet, a powerful attraction, instead of repulsion, is found to ensue between the similar poles. The polarity of the needle, indeed, becomes reversed by the overpowering influence of the bar magnet. This simple fact demonstrates, that the power of developing electric attraction and repulsion is not absolutely inherent either in the electric matter itself, or in the matter acted upon. The movements of the pith balls, and other bodies employed as standard tests of electric action, are therefore contingent effects produced, dependent on modifications of the propagation of the electric impulses.

This fact being admitted, it appears certain that the obvious mechanical effects of the movements of the pith balls, or other parts of the electroscopes, or of other freely movable bodies toward and from each other, cannot be truthfully adopted as final standard tests to be relied upon for determining the principles or laws of the science of electro-dynamics, without a previous knowledge of the laws that govern the specific movements of bodies toward and from each other. Besides, it perfectly transcends all laws of mechanical science to suppose, for a moment, that electric matter at rest, or indeed any other kind of matter, can propagate impulses of mechanical force, such as must take place to sustain the divergency of pith balls in opposition to the incessantly repeated impulses of gravitation. Matter must be in motion in order to propagate motion to other matter; it must be urged to move in order to propagate action.

In all cases of the opposite directions of the movements of bodies, toward or from each other, except the preceding one of the reciprocal attraction and repulsion of the pith balls and gold leaves of electroscopes, every one unhesitatingly ascribes these opposite mechanical effects to oppositely directed impulses of mechanical force. But in construing the phenomena of electric attraction and repulsion, electricians have disregarded researches into the originating mechanical causes of the oppositely directed impulses, as producing the effects of the oppositely directed movements of passive matter. These necessary preliminary researches have not only been overlooked by the authors of the two present popular theories of electricity, but have even been precluded, by summarily ascribing the cause of the movements of the two pith balls, and of gold leaves of electroscopes toward and from each other, directly to "inherent powers," and "innate properties of matter."

Thus, the very matter, which by the laws of mechanical science is adjudged to be incapable of putting itself in motion when in a state of rest, or of stopping itself when put in motion, is affirmed by the electrical theories of both Dufay and Franklin to be not only capable of originating self-motive, but also self-directive impulses. By this bold and unwarrantable disregard of the established laws of mechanical science, it has been assumed that Inorganic lifeless matter is actually endowed with powers even transcending those of the living Organic matter of the bodies of intelligent animals. For the source of the animal motive power developed by living organic matter has been traced to the combustion, in the mechanisms of animal bodies, of the food mechanically produced by the electro-dynamic action of the sun. Animal bodies are endowed with no absolute self-motive, or self-directive powers; the former being contingent on the functions of mechanisms designed to propagate the electro-mechanical action of the sun, and the latter on a temporary endowment of an unmechanical and immaterial essence of a controlling intelligence. The two excited pith balls of an electroscope move in precisely opposite directions in a straight line joining their centres, even amid the obscurity of darkness, which is more than two living animals can accomplish, even at mid-day. Admitting the lifeless matter of electroscopes to be endowed with inherent self-directive powers, this attribute is therefore more mathematically perfect than human intelligence.

If we suffer ourselves for a moment to be led away from the established laws of mechanical science, that "matter cannot put itself in motion," in pursuing researches into the science of electro-dynamics, we leave behind us all landmarks to direct our course; and put forth, without compass or chart, upon a misty sea, where all is shrouded in the obscurity of doubts and conjectures.

For these good and sufficient reasons, the preceding instrumental electroscopes will be considered, simply, as so many tests of the actual directions of impulses of mechanical force, propagated through the medium of electric matter between approximated bodies. The source of these impulses, it is the appropriate province of mechanical philosophy to trace out. The phenomena of electric attraction and repulsion developed by the use of electroscopes, will therefore be no further relied upon in our future inquiries, than as tests of the opposite directions of impulses of mechanical force, propagated through the medium of electric matter.

This fundamental principle will be steadfastly pursued in tracing out the sources of the motive power, producing the movements of portions of passive matter reciprocally, toward and from their respective centres, popularly denominated Attraction, Repulsion, and Polarity.

THE PHENOMENA OF ATTRACTION AND REPULSION OF THE PARTS OF ELECTROSCOPES AND GALVANOSCOPES CONSIDERED, AS TESTS OF THE PROPAGATION OF MECHANICAL ACTION, IN SIMILAR AND DISSIMILAR DIRECTIONS, THROUGH THE MEDIUM OF ELECTRIC MATTER.

The investigation of the preceding facts is here anticipated, at the very threshold of entering upon the subject of the

Dynamics of the Mechanics of Nature, as an indispensable preliminary plan of first establishing a just comprehension of the instruments which are to be referred to as standard tests to decide fundamental principles of science. Although this plan may be out of the ordinary course, yet the propriety of pursuing it must be sufficiently apparent.

When electric excitation is developed on a body insulated upon a glass pillar,—by suspension from a silk thread, or otherwise, it has been usual to denote the mechanical action on the movable parts of the electroscopes attached thereto, by the classification of "Statical Electricity." This classification carries with it the idea, that because a body is insulated, by the intervention of non-conducting substances, from the mass of the earth, that the electric matter having no egress therefrom, must consequently be stationarily confined, like the inhabitants on an island, and thus debarred of freedom of motion. It has not been duly considered that the electric matter on an insulated conductor has freedom to move thereon, like the active inhabitants of insulated tracts of land.

If we admit the electric matter on an insulated conductor to be at rest, there is no other cause left, but to consider the electro-mechanical impulses developed between the two pith balls or gold leaves of electroscopes, to be due to inherent, self-motive powers, as the present popular theories of electricity affirm.

The continuous divergency of the pith balls of electroscopes, suspended from insulated conductors, in opposition to the continuously repeated impulses of gravitation, tending to produce their descent and drooping, side by side, is an indisputable evidence of the fact of the incessant propagation of electro-mechanical impulses. This conclusion is unavoidable; and being admitted, then it follows that electric matter must be endowed with the inherent power of propagating a continuous succession of mechanical impulses adequate to moving grosser matter without moving itself from its state of rest on an excited insulated body. Taking this view of the continuous elevation of the pith ball of the quadrant electro-matter, fig. 14, against the continuous impulses of gravitating force, every instant repeated, it is impossible to conceive that electric matter can continuously self-originate impulses and motion of gross matter, whilst it remains itself motionless. It must move in order to propagate motion to other matter, or else other matter must be endowed with similar inherent, self-motive, and self-directive powers.

These conclusions being inadmissible, in accordance with the laws of mechanical science, as before stated, we have no choice left but to regard the oppositely directed movements of portions of matter toward or from each other, denominated "electrical attraction," and "repulsion," to be simple mechanical effects, produced by oppositely directed impulses, as before noticed, however they may originate, and however they may be modified.

As the science of electricity is entirely based on the tests of the movements of the pith balls, or other parts of electroscopes and galvanoscopes, toward and from each other's centres, the study of the phenomena of these movements is of primary importance. A mistake, in construing them rightly, must impair the truthfulness of any theory which may be based thereon. The science of Electro-dynamics being based on the states of rest and motion of matter, constituting the Statics and Dynamics of the science of Mechanics, will therefore be considered as governed by the same common laws. In adopting the tests of the movements of the matter of electroscopic instruments, human intelligence has virtually appealed to the tribunal of mechanical laws; and, in an appeal to this tribunal, by these laws must Electro-dynamic science be adjudged.

Considering, then, that electric matter, like all other matter, must be in continuous movement to propagate continuous impulses and movements to other matter, recourse must necessarily be had to experimental demonstrations of the actual movements of portions of matter producible by the propagation of electro-dynamic action in various relative directions along the approximated parts of bodies.

PHENOMENA OF ATTRACTION AND REPULSION BETWEEN PORTIONS OF MATTER SERVING TO PROPAGATE ELECTRO-DYNAMIC ACTION IN SIMILAR AND DISSIMILAR DIRECTIONS.

All the movements of portions of terrestrial matter, exhibiting the phenomena of ELECTRICAL and MAGNETICAL ATTRACTION, REPULSION, and POLARITY, are producible at pleasure simply by VARYING THE DIRECTION of the electro-dynamic action through approximated bodies, as we shall now proceed to show.

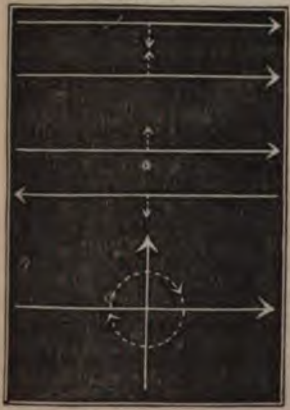
These fundamental principles of the science of electro-dynamics admit of more impressive illustrations by means of the following diagrams, arranged in accordance with the discoveries of these facts originally made by the celebrated French philosopher, Ampère.

The long arrows in the following diagrams represent the approximated conducting wires or the sides of any approximated conducting bodies serving to propagate electro-dynamic action.

The short dotted arrows represent the resultant lateral electro-dynamic action, producing the relative movements of such conducting bodies, and the consequent phenomena of

Attraction, Repulsion, and Polarity.

Fig. 24.



ATTRACTION between similarly directed—

REPULSION between oppositely directed—

POLARITY between transversely directed—

Electro-dynamic impulses.

The INTENSITY of electro-dynamic action between specific points of bodies serving as the pathways of electric currents, is found to become diminished in the inverse ratio of the squares of the increased distances, in accordance with the laws which govern the force denominated Gravitation.

But the total electro-dynamic action of the side of one infinitively extended body upon another similar body, is diminished in the simple ratio of the increased distances, as is manifest from the fact, that the parts of such bodies must necessarily be opposite to each other throughout.

It will be noticed that the phenomena of *polarity* is simply the tendency of transversely directed electro-dynamic impulses to become arranged in *similar directions*, *by turning about the bodies serving as their respective pathways*, as denoted by the circular arrows in the preceding diagram.

Hence we cannot avoid the conclusion that the phenomenon of *attraction* and *repulsion*, however diverse they may appear, are alike resultant effects produced by the conjoint action of two transversely directed impulses, as denoted by the term POLARITY, or POLARIZATION.

By carrying out this simple idea of the general tendency of the propagation of transversely directed electro-dynamic impulses between approximated bodies to turn them about to similar directions, we are furnished with a key for explaining all the various phenomena of the movements of portions of terrestrial matter, reciprocally, *toward* and *from* as well as *about* each other's centres.

The propagation of mechanical impulses must necessarily take place in space through the medium of matter. All space not occupied by elementary substances, has been considered to be occupied by electric matter. In the latter case space is popularly deemed to be *void*.

When the propagation of mechanical action takes place through void space, it must be supposed to be effected through the medium of electric matter only, as is the case of the propagation of the electro-dynamic action of the sun through the void space of the heavens in the modified form of light and heat. When the action is propagated through space partially occupied by fluids, such as atmospheric air and gases, it is accomplished by displacing the particles in the line of propagation in the modified form denominated "disruptive discharges" of lightning and of electric sparks, and "convective discharges."

When mechanical action is propagated to a distance, from atom to atom, and mass to mass, without displacing them, this mode has been denoted "Conduction of electricity."

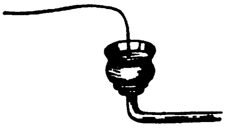
And when the electricity existing in connection with one body is disturbed and induced to move by the movements of other electric matter near it, this peculiar mode of propagating mechanical impulses is denoted " nductive action."

The "conduction" of electric action excited by galvanic batteries, and by slight causes of the disturbance of electric matter, requires intimate contact of the atoms, such as is not requisite where the action from frictional electrical machines is to be propagated. The sparks from these machines take place in disruptive discharges through considerable spaces occupied partially by the air. An intervening space of air of only $\frac{1}{10000}$ of an inch between the ends of the conducting wires of a galvanic circuit, is sufficient to arrest the action from a battery of 12 series of zinc and platinum plates, according to Professor Jacobi's experiments. The obstruction of the least scale of rust or other foreign substance, between the parts otherwise in apparent contact, interferes with the perfect propagation of slight galvanic action. But after the propagation of the action is once established, however, and a void space thus opened as a ready channel through the atmosphere, the action may continue to be propagated from powerful galvanic batteries through an intervening space of several inches.

The mere laying one end of a conducting wire on another, which forms a sufficiently perfect state of contact for the propagation of electricity proceeding from an electrical machine, does not produce a sufficiently perfect state of contact for the transmission of excitation from a small galvanic apparatus. Where two wires are to be connected, they should be previously rubbed bright with fine sand-paper, and then twisted firmly together; or a weight may be placed on them. But in all practicable cases it is best to solder together the parts of conductors. In a series of numerous plates they are commonly soldered together.

In the use of delicate instruments employed as tests of the propagation of galvanic action, it is necessary to arrange the conducting wires so as to be readily separated from the machines, and their junctions do not admit of being soldered. Hence the following contrivances have been adopted. These will here be detailed, in order to show the purposes for which these appendages appear in the various machines exhibited in the following pages.

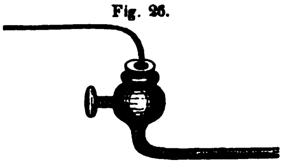
Fig. 25.



Whenever little cups appear in any delineations of machines, of the form represented in the figure, it will be understood that they are designed to contain some mercury, which unites partially with the texture of the metallic vessel that contains it, as well as with the tinned or amalgamated ends of the conducting wires to be plunged therein. This metal thus serves the purpose of a fluid solder, admitting of the free separation and contact of wires forming battery circuits.

But as this mode of arrangement leaves the ends of the wires loosely immersed in the cups, and liable to fall out, recourse has been had to the substitution of cups having a binding thumb-screw, as shown in the figure. An intense pressure is effected on the ends of the wire, rubbed bright with sand-paper. A more perfect state of contact, as well as permanency of the connection, is thus available. This contrivance is termed a Screw-cup. As the metal platinum remains bright and free from crusts of rust, it serves very perfectly for forming efficient connections by simple contact.

Fig. 26.

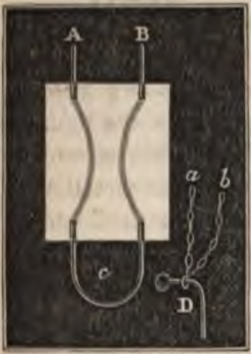


To insure perfect propagation of electro-dynamic action through the parts of the dry skin covering the body, it is necessary to moisten them with water.

For the preceding reasons, a simple coating of thread wound around conducting wires, as bonnet wires are coated, is found to be sufficient to insulate them from each other, even when wound together compactly into spiral coils.

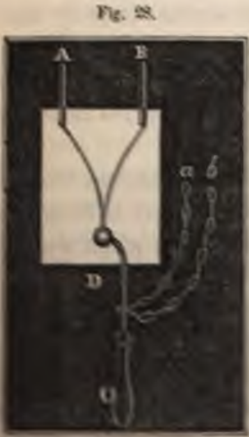
The propagation of electro-dynamic action between two bodies by disruptive discharges of electric matter in the void space of the bell-glass, although exceedingly beautiful in lambent flashes, appears to exhibit no decisive character either of attraction or repulsion, as might be theoretically anticipated of the movements of a homogeneous fluid. But when the electro-dynamic action is propagated through the atmospheric air, a reciprocal attraction between the lines of the propagation of the impulses becomes manifest, as has been represented by experimenters in the annexed cut. Two coated glass jars, charged from an electrical machine, are arranged with their respective outer coatings connected severally with the two wires, A and B, and with their respective inner coatings connected by the chains, *a*, *b*, with the small knob of the discharging rod, D. A bended wire, of an U shape, is arranged at C, upon a white enamelled visiting-card, or on a card coated with vermilion, such as is used on common playing-cards. The propagation of electric action over the surface of the enamel or vermilion leaves a black track, which serves to denote the direction of the course of a disruptive discharge.

Fig. 27.



When the discharging rod, D, is brought near C, a disruptive action ensues, and the two jars become simultaneously discharged. It is commonly found that a convergency of the blackened tracks appears marked on the card. Were there no reciprocal attraction between the two lines of propagation of electro-dynamic action, the tracks would be in parallel straight lines, instead of curving toward each other, as delineated by their shaded pathways.

Fig. 28.



Let the direction of one of the currents be reversed, and the tracks will be found to separate from each other by a convex curve. When a disruptive spark is discharged between the wires, A, B, Fig. 28, connected, as before stated, with the two external coatings of the glass jars, and the knob of the discharging rod, D, connected by the chains, *a*, *b*, with the interior coatings of the jars, the blackened tracks left on the surface of the white enamelled card will show that the direction of the discharge is not in a straight line from D severally to A and B, but that they coalesce for a short distance, and then diverge, leaving tracks resembling the outlines of the letter Y, rather than of the letter V, which would be the case were there no attractions between the currents.

To render this experiment successful it has been recommended to arrange the ends of the wires, A, B, about one-third of an inch apart, with a greater space intervening between the opposite wire.

But these experiments are less conclusive than those in which the electro-dynamic action is propagated along the surfaces of two approximated solid portions of matter, the movements of which are more distinctly observable, and are also more conclusively demonstrative of the effects of mechanical impulses. The preceding experiments serve, however, beautifully to illustrate the phenomena of the forked appearance of the flashes of lightning in the sky, as the collasping electric discharges become reciprocally attracted to unite, like the commingling currents of rivers, as will presently be recapitulated with reference to the preceding phenomena.

After the discovery of the galvanic battery, experimenters were enabled to ascertain the effects producible between approximated bodies serving as the pathways of continuous electric currents, or of the continuous propagation of electro-dynamic action along the pathway furnished by conducting bodies.

Metallic wires have been selected as affording greater facilities for making experiments to ascertain the effects of the propagation of electro-dynamic action; but the same effects are producible in other kinds and forms of terrestrial matter. Much ingenuity has been exercised to arrange the parts of rigid conducting bodies near each, so as to allow the freedom of motion to slight electric action. Small, and apparently insignificant as some of these artificial machines and experimental exhibitions may appear to a superficial observer, yet it is to be remembered that the principles of action, which govern the states of rest and motion of all the minutest parts, govern the conditions of the whole.

In the annexed figure, A and B represent two wires, bended to a rectangular shape, and balanced in a vertical position, with a ball serving as a counterpoise weight, screwed upon the lower with mercury, with its lower extremity just dipping into it. The electric current is transmitted from one of the binding cups of the base-board, up the brass pillar to the coil, and downwards through the coil to the mercury, which is connected by a wire, passing out of the bottom of the cup, with the other binding cup.

Whilst the action is propagated throughout the circling coils of the wire, they are severally urged toward each other, whereby the length of the coil of flexible wire becomes shortened sufficiently to lift the end of the wire out of the mercury. At the instant this is effected, the circuit of the current is broken, and the coil resumes its former length, dropping the lower extremity of the wire back into contact with the mercury, thus renewing the circuit of the current. This operation being rapidly repeated, the elastic coil of wire is kept quickly vibrating up and down with a churning movement, which is sustained as long as the battery current is transmitted through it.

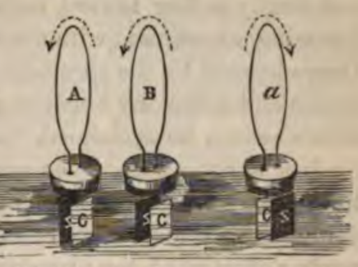
A more rapid and vigorous action ensues if a bar magnet, or bar of soft iron be introduced into the coil.

Not only is the fact of the reciprocal movement, *toward* and *from* each other, of two bodies, serving as the conductors for propagating electro-dynamic action thus demonstrated, but even in the statical arrangements of the relatively fixed positions of all terrestrial matter are thus also producible, as exhibited in the phenomena of Terrestrial Magnetism, and Polarization of magnetic bodies, and in the cohesive conditions of groupings of atoms into fixed aggregations of solid bodies.

It is a task requiring the exercise of much ingenuity to arrange wires, and other conducting bodies, in such a manner as to be freely movable in every direction, in obedience to the electromotive impulses imparted to them, and at the same time to maintain continuously the connection with the galvanic battery, from which the electro-dynamic action is propagated. This difficulty was first surmounted by the ingenuity of De La Rive, in the year 1821. He attached each of the wires to be experimented upon to a little floating galvanic apparatus, as shown in the figure;
ere C and Z represent very small zinc and copper plates ar-
d opposite to each other, and suspended from pieces of
oating on the surface of acidulated water. The wire con-

necting each plate of zinc and copper is passed through the cork, and bended to the shape of a ring, as at A B and *a*.

Fig. 31.



The propagation of the electro-dynamic action is from the zinc to the plate of copper beneath the acidulated water, and from the copper back to the zinc in a returning circuit above the liquid, as denoted by the dotted arrows. These pieces of wires or rings form distinct little floating galvanic batteries, freely movable in obedience to the electro-dynamic impulses; and when set afloat near each other, they exhibit by their relative movements, very perfectly, the verification of the preceding phenomena of attraction between bodies propagating electro-dynamic in similar directions, and of repulsion between bodies propagating the same action in opposite directions.

The rings A B, about which the action is propagated in similar directions, as denoted by the dotted arrows, will sail *toward* each other, exhibiting the phenomenon of attraction.

The rings *a*, B, about which the action is propagated in dissimilar directions, will sail *from* each other, exhibiting the phenomenon of repulsion.

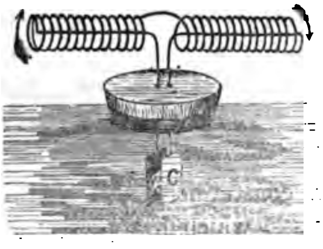
After performing a circuitous voyage, they will gradually become turned around, so as to present toward each other their respective sides or poles, about which the currents circulate in similar directions; when they will finally move toward each other.

These pieces of wire, whilst they serve as pathways to propagate the electro-dynamic action about the circuits of their respective parts, as shown in the preceding figure, are found to behave toward each other precisely like two small magnetic needles, set afloat on the same pieces of cork.

It is narrated that an ancient Grecian philosopher once took two small fragments of a certain kind of magnetic iron ore, termed the "load-stone," and experimentally set them afloat on two chips of cork. He became impressed with wonder when it is usual, in practice, to include as many circuits of coated or insulated fine wires, as is compatible with the portability of the apparatus, for the purpose of exhibiting more energetically, the resulting movements.

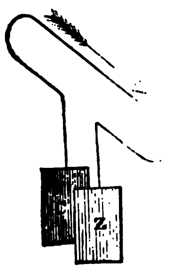
To exhibit the identity of electro-dynamic and magnetic action more manifestly, recourse was had by Ampère to both multiplying and extending the circuits of the electric action about numerous spirals of the conducting wire, as shown in the figure. He wound a piece of fine wire around the tube of a quill in the spiral form of a corkscrew, and bended back the two extremities within the interior of the tube thus formed, until they returned to the centre. Here he bended them downwards and passed them through a piece of cork. At the lower ends of the two wires a plate of zinc and copper of the size of the thumb nail, Z C, are attached by soldering. This tiny apparatus is to be set afloat in a basin of acidulated water, as previously recapitulated, when it will be found to behave, in every respect, precisely like a magnetic needle. One particular end or pole will always become turned toward the north, however often it may be deflected from that position by disturbing counteracting causes. If a magnetic needle be set afloat on another piece of cork, they will act and react on each other in every respect, as two magnetic needles do.

Fig. 24.



To prove experimentally the fact that the propagation of electric action about the circumference of bodies is capable of developing impulses corresponding with the direction of similar or dissimilar approximated electric currents, it is only necessary to bend another piece of similar wire to the form shown in the figure, and to solder to one end a plate of copper, C, and to the other a plate of zinc, Z.

Fig. 25.



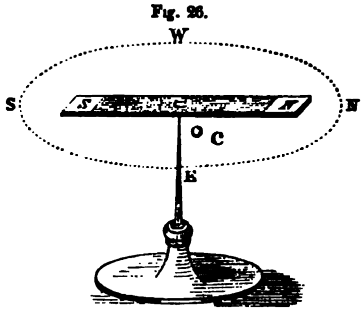
If the wire with the plate of zinc and copper attached be dipped into the acidulated liquid, the current is propagated toward the eye of the spectator, whilst beneath the under sides of the spiral coil it will be noticed that the current is propagated in an opposite direction. On holding this wire beneath the spiral coil, it will be found, on the principle that oppositely moving currents produce the phenomenon of repulsion, that the cork sustaining the floating wire will sail away. After making an apparently mysterious circle about the lower wire, it will finally return, and remain permanently stationary in such a relative position, that the current moving about its under surface in proximity to the conducting wire beneath may become arranged to the same coinciding direction: and however often turned around or moved therefrom, it will finally float back to this one specific position, always standing with one end or pole of the projecting coil *crosswise* of the wire beneath it. By gradually turning the direction of the lower wire to point toward the various quarters of the horizon, the spiral coil will follow every change of the direction of the current, propagated through the wire beneath it. On withdrawing the lower conducting wire beyond its influence on the floating coil, the latter invariably turns to such a relative position in regard to the points of the compass, that the electric action or current, circulating about its lower side next to the surface of the earth, may move in a direction from east to west.

This fact conclusively demonstrates that the spiral coil, in the absence of the overpowering propagation of the electro-dynamic action along the conducting wire beneath it, yields to the less immediate and comparatively less intense propagations of a similar electro-dynamic action, naturally circulating about the circumference of the earth's surface in the specific direction from east to west. Thus, by means of this electroscopic test, it is demonstrable that electric action is propagated continuously from east to west, about the earth's surface.

If a magnetic needle be similarly set afloat in place of the spiral coil, and the same copper wire with its appended copper and zinc plates be held beneath it, its movements will be found to correspond in every respect with those of the spiral coil, and it will always finally settle in a position *crosswise* of the conducting wire beneath it.

The discovery of this latter fact by Oersted, in the year 1819, constituted an era in the science of electro-dynamics; for it disclosed, for the first time, to the comprehension of human intelligence, the true character of the magnetic needle of the surveyor's and mariner's compass, as being a real electroscopic instrument.

Fig. 26.



The preceding result of the crosswise position of a conducting wire and magnetic needle is exhibited in the figure 26; where the needle is supposed to be arranged in its natural north and south position, as denoted by the points of the compass N, S, E, and W. The terrestrial currents advance from the east, and are represented by the sectional view of a conducting wire C, *beneath* the needle.

If the direction of this conducting wire be gradually turned from pointing toward the west, to point toward the south, the north pole of the needle will become simultaneously turned to point toward the west, and will keep its same relative position in advance of the changing direction of the overpowering action of this artificial current, C, until it has been chased entirely around the circuit of the horizon.

As the magnetic currents circulating around the axis of the magnetic needle must necessarily move over the upper side of it in an opposite direction to that in which they move in their circuit around the under side of the needle, it follows of course that if the conducting wire C be held above the needle, the relative positions of the north pole will be reversed also, or the opposite south pole will now take the place of the north pole.

The same rule will also denote the positions which the needle, if freely movable as a *dipping needle*, will be caused to assume by the action of vertically directed currents.

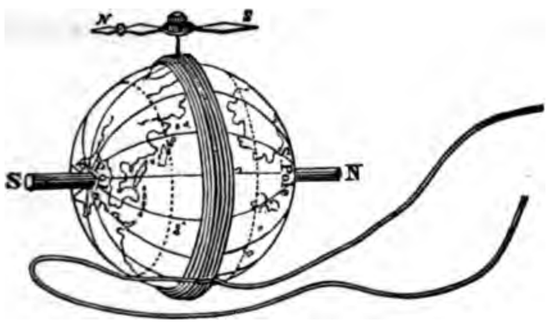
The preceding experiments prove two very important facts, viz.:—that electric action is propagated in continuously circulating currents in a specific direction from east to west, about the axis of the earth;—and that a similar continuous circulation is taking place about the axis of every magnetic body.

These two facts serve to explain the true character of a compass needle, when mounted on its pivot as an electroscopic test of the direction of the electric currents circulating from east to west about the circumference of the globe of the earth. Its value is inappreciable for indicating the positions of the relative parts of the earth. The directions of the terrestrial currents correspond with the lines of longitude drawn about an artificial globe, and the magnetic needle always assumes a position crosswise to them, and consequently becomes arranged in a meridional north and south line.

Without recourse to this little instrument, the inhabitants of the opposite shores of wide oceans would be debarred from communication with each other. It thus constitutes the sceptre of man's power over the trackless waters, covering nearly three-fourths of the surface of the terraqueous globe.

To exhibit the true character of the magnetic needle, Professor Barlow mounted it on the top of an artificial globe, with a conducting wire wound round it, as shown in the figure. However this little artificial globe may be turned about in direction in relation to the cardinal points of the horizon, the needle will always faithfully point towards its north pole. The principles of the compass needle are thus beautifully illustrated, whilst its utility becomes also represented in bold relief as surmounting the globe of matter, which it serves to subject to the dominion of man.

Fig. 27.



When a magnetic needle is employed in the service of detecting the presence and direction of the propagation of approximated electric action, it has received the new name of "Galvanoscope."

When it is used to detect the intensity of the propagation.

of the electro-dynamic action, by its greater or less degree of yielding to the impulses which deflect it from its natural north and south position; it has received another characteristic name of Galvanometer, or measurer of galvanic electricity.

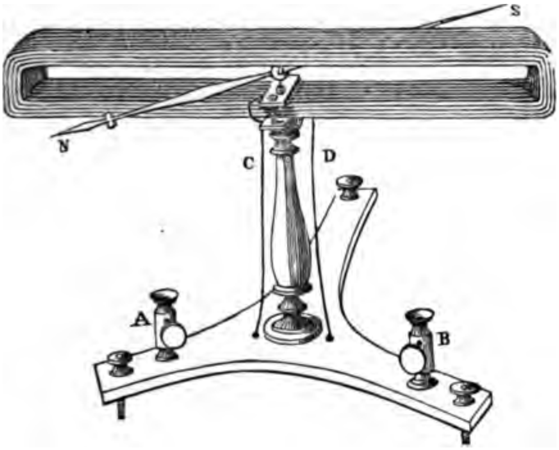
The fact of the propagation of electro-dynamic action in the modified form denoted by the term "electric currents," is judged of by the test of the simple movement of the magnetic needle in swinging around on its pivot. The *degree of intensity* of the electro-dynamic action propagated, is judged of by the test of the extreme extent of the angle of its divergency from its natural north and south position; whilst the *direction* of the propagation of the electro-dynamic impulses near the needle is judged of by the particular crosswise direction in which a particular pole of the needle is turned or deflected to one side or the other.

In order to learn the *direction* of the galvanic current acting on the needle, from beholding its movements, it becomes necessary to have recourse to some artificial association of ideas of the relative effects of the crosswise positions assumed by the needle under varying circumstances. As a simple clue to anticipate in what direction the north pole of the needle will be turned in relation to the direction of the current propagated near it, reference may be had to the position of the compass needle, with its north or *marked* pole pointing toward the north magnetic pole of the earth.

Considering that the terrestrial electric currents, advancing from the east toward, and beneath the needle, cause its marked pole to point toward the *right* hand, or toward the north, it is only necessary to carry out this analogy to anticipate in what direction the same pole of the needle will be turned in every experimental approximation thereto of variously directed electric currents. The north pole will always be turned similarly to the *right* hand of a current advancing toward and beneath the needle.

Schweiger, in Germany, reasoning that if a single current passing directly along on one side of a magnetic needle exerted sufficient force to turn it on its pivot, it might be expected that by multiplying the circuits of the same current about the needle, the intensity of the electric forces would become multiplied to the same extent as the number of circuits, he accordingly wound numerous turns of copper wire (coated with silk to insulate from each other the overlapping coils) about a small piece of board. On withdrawing this piece of board, and inserting a magnetic needle within the cavity of the flattened coils of wire adapted to admit the needle to work freely therein, he constructed the *Galvanometer*—one of the most useful and important instruments now employed for testing the presence of the slightest propagations as well as intensity of electricity in motion; for in passing several hundred times about the needle, both above it and beneath it in the returning convolutions of the wire, its influence becomes correspondingly multiplied. Hence this instrument was originally called a "*Galvanic Multiplier*," as exhibited in the figure. N, S, represents the needle inserted between the multiplied coils of wire, the ends of which, C and D, are extended downwards to the binding screws, A, B, which are used for receiving and confining the ends of the conducting wires connected with the galvanic battery, or other bodies subjected to electric excitation.

Fig. 28.



Whilst this important instrument serves to detect the presence of the slightest current by its sensitive deflections, it also serves to denote the intensity of powerful currents by the extent of its deflections; whilst all doubts about the directions of currents are simultaneously dispelled by the peculiar directions of the movement of the north pole to the east or toward the west, as has been previously narrated.

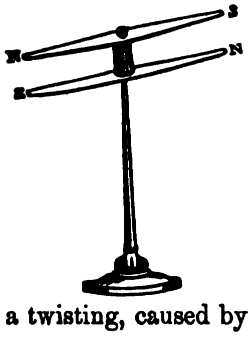
This instrument will be frequently referred to as one of the most sensitive tests of both the direction and intensity of the propagation of electro-dynamic action.

It should be remembered that the galvanometer serves only to denote the *intensity* of the propagation of the electro-dynamic action,—not the absolute *quantity* of electric matter that is disturbed on the surface of the approximated conducting body.

In using the galvanometer to measure the intensity of the electric force by the divergency of the magnetic needle, it is also to be noticed, that the scale of degrees marked on the circle does not denote the absolute force excited. A feeble electric current may cause the end of the needle to swing around over 10°; but by doubling the power of the current, it does not become urged to swing around 20°. The reason for this is obvious, the action of the deflecting force being reduced nearly in the ratio of the square of the distances of the separated conducting bodies and poles of the magnetic needles, and the action of the magnetism of the earth to bring back the needle to its north and south position being increased in proportion as the needle becomes turned more nearly at right angles to the north and south meridional line.

For very delicately testing slight electric disturbances in experiments with the galvanometer, it is usual to employ an Astatic Needle, composed of two needles with their north and south poles reversed and confined together, to neutralize each other's terrestrial magnetism—as shown in the figure. This needle will remain stationary in whatever position it may be turned. The action to be tested is applied to the upper or lower needle, both being environed by spiral coils of the conducting wire.

Fig. 29.

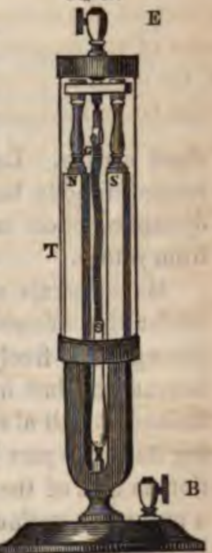


In using a magnetic needle as a *galvanometer* to measure the intensity of electro-mechanical impulses, it is preferable to suspend it by silk cord or fine wire, requiring some exertion of motive power to produce a twisting, caused by the movement of the needle. The *torsional* resistance in this case becomes a test of the extent of the electro-dynamic action; whilst the deflections of the needle may be limited to a range of only about 20°.

A galvanoscope constructed on the plan of an astatic needle, and arranged within the multiplied coils of a conducting wire, is an exquisitely sensitive test of the presence of the least disturbance of the natural electro-static conditions of bodies. If a fine conducting wire of copper be connected with the binding cup A, and another of zinc with the cup B, the mere dipping the points of these fine wires into dilute acid, will cause the needle to move; and even the holding of the ends between the warm fingers will also produce the same dynamic action; as will be presently noticed more particularly in treating of "Thermo-electricity."

In the action of the current, traversing the wire coils as shown in the preceding figure, upon the magnetic needle contained therein, there is an equal and opposite reaction of the magnetic needle upon the wire, on the established principle of the science of mechanics, that action and reaction are always equal and in opposite directions. If the magnetic needle were fixed stationarily, and the wire arranged to turn like the needle on a pivot, it would behave like the needle.

Fig. 30.



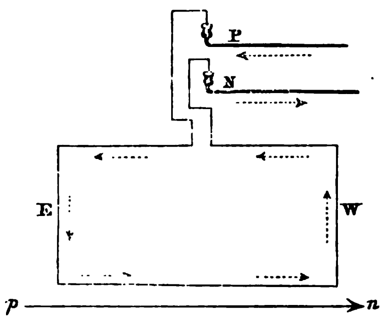
On this principle of the reaction of a magnet on an approximated conducting body has been constructed an exceedingly sensitive galvanoscope; wherein a piece of flexible gold leaf has been selected for exhibiting the mechanical movement, and the magnet remains fixed, as shown in the annexed figure.

A horse-shoe magnet, T, is used in this case, erected vertically on a stand, and the strip of gold is extended between the two prongs, the electro-dynamic action being propagated either upwards or downwards between the screw-cups B and E. The gold leaf is inclosed in a tube of glass to prevent its agitation by currents of air.

When the current is propagated downwards from B, the gold leaf will become urged, not toward one pole N, or toward the other pole S, but in an intermediate direction *from* the spectator. And when the current is caused to ascend the gold leaf, it will be swayed forward in a line *toward* the spectator. The facts of this particular direction of impulses will hereafter be particularly explained in accordance with established laws of electro-dynamic action.

To exhibit the effects of movements of bodies resulting from the reciprocal action and reaction of transversely directed currents, a light, freely-movable frame of wire, suspended as shown in the figure, may be conveniently employed.

Fig. 31.



Let E W represent a conducting wire of a rectangular form, rendered freely movable on the inverted points P N, resting in small cups filled with mercury. The propagation of the electric action is from a galvanic battery, entering at P, and traversing the frame throughout in the directions shown by the short arrows. Let *p n* represent another conducting wire, arranged directly beneath E W, and serving to propagate electro-dynamic action in the direction indicated by the arrow-head, from *p* to *n*.

Experiments with this simple apparatus demonstrate, that whilst the electro-dynamic action is propagated simultaneously through the freely-movable wire-frame, and through the wire beneath it, that in whatever direction the frame may be swung around, it will always be turned about, until the current traversing its lower part becomes arranged in precisely the same direction as that of the approximated current *p n*; and by turning *p n* around in various direction transversely to the lower side of E W, the frame will be found to become simultaneously turned about, so as to permit the current traversing the side nearest *p n*, always faithfully to conform to a similar direction.

By supposing the short lateral arrows in the following diagram to represent the directions of the electric actions transmitted along the lower side of the frame, suspended immediately over the extended current *p n*, as viewed from a vertical position, by looking down upon the frame and the extended conducting wire beneath it, there is presented at a glance a perfect

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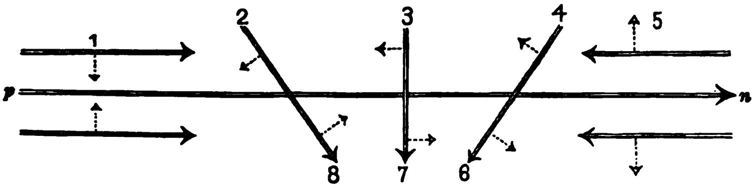
ELECTRO-DYNAMIC KEY OF THE RECIPROCAL ACTIONS AND REACTIONS OF VARIOUSLY DIRECTED ELECTRIC CURRENTS.

Fig. 32.



In the preceding diagram, the short dotted lateral arrows are designed to denote the movements of the lower side of the wire frame, resulting from the reciprocal electro-dynamic action between it and the conducting wire *p n*, arranged under it.

It will be perceived that the several transverse movements, denoted by the short lateral arrows, are in accordance with a rotary tendency about a common centre, at a point where the currents cross each other. This rotary tendency is in accordance with a general law governing all reciprocal actions of approximated electric currents on each other, or rather between the approximated bodies serving as their respective pathways.

By comparing the directions of the short dotted lateral arrows from 1 to 8, it will be found that they all indicate a tendency of the frame to become turned about, so as to allow the approximated currents to move in *similar directions.*

The apparent "repulsion" becomes resolvable into an incipient movement, tending to bring the directions of the propagation of electro-dynamic actions to coinciding directions, to allow of a final reciprocal attraction. Thus the phenomena of *Repulsion* may be considered as an incipient stage of the turning about of bodies to allow of the propagation of electro-dynamic action along their approximated parts in similar directions, and of the consequent final result of *Attraction.*

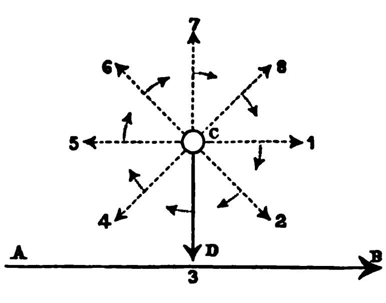
The term *Polarization,* therefore, represents the reciprocal action and reaction between all approximated portions of matter serving to propagate electro-dynamic action in any other than parallel directions. As this turning about of all freely movable bodies to allow the currents propagated over their approximated parts to move in similar directions is an inseparable consequence of the reciprocal action and reaction developed by the propagation of electric currents over them, it follows that Polarization must be an universal electroscopic test of the presence of electric currents traversing the adjacent sides of bodies.

The movements of the extended conducting wire *p n,* if perfectly free to move, would be in precisely opposite directions to those of the shorter lateral wires, on the principle that action and reaction must always be equal, and in opposite directions.

By scrutinizing the directions of the lateral dotted arrows, indicating the resultant action on each of the conducting wires numbered from 1 to 8, in the Electro-dynamic Key, it will be discovered that they combine to produce a harmonious system of rotary movements, in whatever position they may be successively placed.

In the annexed diagram, the several relative positions of the lateral currents 1 to 8, on one side of a prolonged current, A B, are relatively compared. If a movable conducting wire, C D, were hung on a pivot at C, it should be urged to revolve continuously; for in whatever relative position it becomes arranged, the short lateral arrows denote it to be continuously urged to move at right angles to the line of direction of the propagated electro-dynamic impulses.

Fig. 33.



That a continuous revolving movement is actually producible in a body serving as the pathway to propagate electric action in the mode represented theoretically in the preceding figure, will presently be illustrated experimentally.

By arranging the wire frame so as to present a current *terminated on one side of p n*, as directed in the Electro-dynamic Key, by 3 and by 7, it will be perceived by the direction of the dotted lateral arrows, that if the current *approach p n* at right angles thereto, that the wire frame will be urged to move bodily in a direction *exactly opposite to that of the current p n ;* whilst on the other side, the continuation of the same direction of the current *receding* at right angles from *p n*, will urge the wire frame to move bodily in a direction *exactly similar to that of the current p n.*

These two opposite, and otherwise apparently anomalous movements of bodies propagating electric action terminated on *one side* of an extended conducting body, are readily explainable, on the simple principle of their incipient movement to become arranged in coinciding or similar directions, as if both ends of the arrow, 3 7, were beginning to turn on the point of its intersection with the current *p n.*

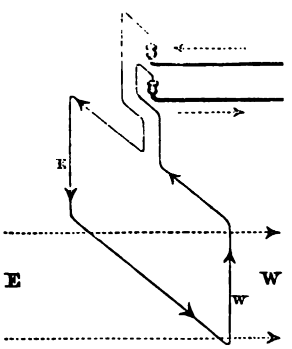
If, therefore, the lower side of the wire frame be arranged on one side of *p n*, so that it may represent the wire 3, or 7, the whole frame will be actually moved bodily along the conductor *p n* in an *opposite* direction to the current propagated through it on one side, as shown at 3, and in a *similar* direction with it if placed at 7, as the dotted arrows denote.

This is a very remarkable result of the action of all polarized bodies, and will be hereafter particularly noted.

In calculating the effects of the action of an extended current on a current propagated about the four square sides of the frame E W, or about the circumference of a circular approximated body or sphere, the consideration of the reciprocal action of the currents traversing the remaining three sides of the rectangular frame E W, figure 31, or the circuit of Ring of De La Rive, figure 22, is by no means to be overlooked. Although the immediate proximity of the lower side of the frame to the current *p n* may render the reciprocal action between them so much more immediate and intense, as to overpower the more distant and consequently feeble reciprocal actions between *p n* and the two vertical and upper sides, yet when we come to apply the more generally diffused action of the terrestrial electrical currents upon the four different directions of the current traversing the four sides of the frame, considerations of the reciprocal actions of all these four currents, directed oppositely to each other in pairs on opposite sides, require to be taken into account.

The frame E W, as represented in the annexed figure, is arranged crosswise of the horizontal currents beneath it, which are designed to represent the terrestrial electric currents flowing from East to West. Although the tendency of the current traversing the lower side is to swing the ends of the frame from E toward E, yet on observing the upper side of the frame it will be noticed that the current is there propagated in a precisely opposite direction to that on the lower side, as denoted by the opposite direction of the arrow heads. Considering the relative distance of the upper and lower sides of this frame from the general terrestrial currents, (which have been found to exert nearly undiminished action at the height of above four miles from the earth's surface, as tested experimentally by an adventurous aeronaut,) to neutralize each other, we have only to regard the reciprocal action and reaction between the terrestrial electric currents and the vertical currents at E and W, as determining the movements of the frame. This same reasoning applies also to the movements of the floating Ring of De La Rive and of compass needles.

Fig. 34.



The mechanical movements of the magnetic needles of the surveyor's and mariner's compass on its pivots, by the action and reaction of the current traversing the circuit about their axes or their four sides, on the currents traversing from east to west about the earth's surface, is therefore ascribable to the vertical portions, descending at E, and ascending at W.

That this result is demonstrable, we shall now proceed to show by reference to the preceding Electro-dynamic Key.

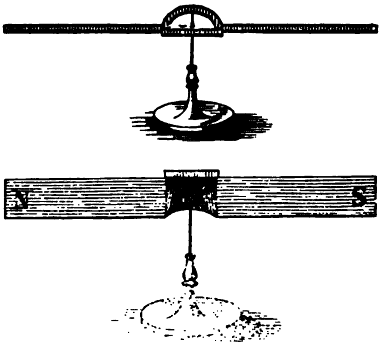
The vertical direction of the portion of the currents descending the side of E, is represented by No. 3 as approaching the extended horizontal current *p n*. The short lateral arrow at

No. 3, denotes that a body serving to propagate a vertical electric current, toward another horizontal one, will be moved horizontally in an opposite direction thereto.

The vertical direction of the current on the side W, is represented by No. 7 of the Key, as receding from the current *p n*. The short lateral arrow there denotes that a body serving to propagate an electric current from another, will be moved horizontally in the same direction in which the current moves.

. By considering the action of both these two oppositely directed impulses on the two opposite ends of the frame at E and at W, it will be discovered that they both conspire to swing it around on its pivots. We are hence to consider the movement of this frame, and of every magnetic needle in a compass, to be due to the vertically directed currents about its sides, and not to those traversing horizontally the upper and lower surfaces. Considering that if the preceding theoretical calculations were truthful, a greater comparative intensity of electro-dynamic action might be developed by extending the vertical sides of a magnetic needle, and by contracting the horizontal sides, I caused a needle to be made of the form shown in the figure, capable of being mounted on its pivot either *flatwise* as in the upper figure, or *vertically*, as in the lower one. The needle is eight inches long, three quarters of an inch wide, and one thirty-second part of an inch thick, balanced on the acute point of a fine sewing needle.

Fig. 35



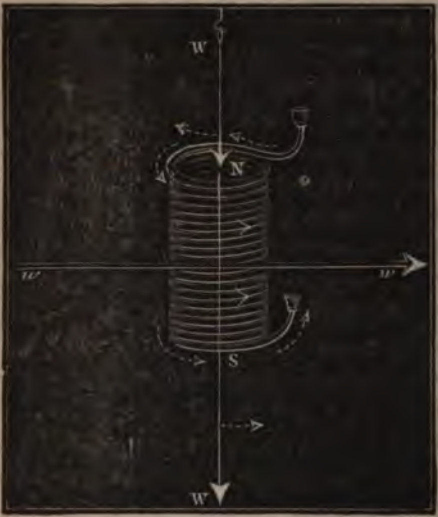
By this peculiar mode of varying the suspension of the same needle, at pleasure, either flatwise, or edgewise, if there be any difference of the action of the terrestrial electric currents on the vertical and horizontal currents about the needle, I calculated that the fact might be thus verified.

Placing the needle in the position shown in the upper figure, and arranging the direction of the pole to point toward the south in the line of the magnetic meridian, it was set free and left to revolve on its axis. The number of vibrations were noted, which the needle made before it came to a state of rest in its natural north and south static condition; and also the time which elapsed during the vibrations. By the average of many trials, twenty-one vibrations were made in $2\frac{75}{100}$ minutes.

Turning the needle to a vertical suspension in the position shown in the second figure, and repeating the same experiment by many trials, I found the average to be increased to 27 vibrations in $3\frac{31}{100}$ minutes.

Judging from these experiments, the preceding theory appears to be practically verifiable, thus showing that the present common mode of the suspension of compass needles *flatwise*, is not the most effective for accomplishing the purposes for which such needles are employed.

Fig. 36.



The crosswise position which a magnetic needle assumes in relation to a body serving to propagate electric action near it, as discovered by Oersted, and shown by figure 26, admits of a simple illustration by considering the magnetic needle to owe its peculiar powers to the continuous propagation of electric currents about its axis in accordance with the theory advanced by Ampère. A cylindrical steel magnet may be represented by a spiral coil of conducting wire, N, S, in the annexed figure, with currents propagated from a galvanic battery through the connecting cups in the direction denoted by the dotted arrows. All the relative movements of a freely movable conducting wire, W, W, in connection with this spiral coil, will be precisely similar to these which will take place when the same wire is brought near a regular steel bar magnet. They admit of perfect illustration by reference to the electro-dynamic key, fig. 32, and by the application of the simple principle that all approximated bodies serving to propagate electro-dynamic action are urged to turn, so that such action may be propagated in both bodies in similar directions.

About the top of this cylinder the direction of the current is shown by the dotted arrows to be *opposite to the movements of the hands of a watch about the dial-plate;* and if the lower end of the cylinder were turned up toward the eye of the observer, it would show the direction of the current, indicated by the dotted arrows, to be in the *same direction as the hands of a watch move.* It is found experimentally, that the former direction of circulating currents at N, exhibit all the characteristic properties of the *north pole* of a magnet, and the latter at S, the properties of the *south pole* of a magnet. By impressing this fact on the memory, the specific north or south polarity produced by the circulation of electric currents, may be readily determined by inspection. It will be noticed that the portion of the current, W N, approaches the current about the top of the cylinder at N, and the portion of the current, S W, recedes from the current about the lower end of the cylinder at S. By referring to the electro-dynamic key, page 235, it will readily be ascertained that W N represents No. 3, and S W represents No. 7; the former producing the resultant movement in an *opposite direction* to that of the current which acts upon it, and the latter in the *same direction*, as denoted by the short lateral arrows affixed to these approaching and receding portions of the current.

Supposing the upper end of the conducting wire, W, to be freely movable, by being suspended on a hook joint, it is manifest on inspection of the direction of the short lateral arrow, that this electro-dynamic action must impart to it a continuous revolving movement about the circuit of the N pole of the electro-dynamic ring, *in the same direction* as the hands of a watch move about the dial-plate; although the current beneath it actually moves in the opposite direction thereto.

This theoretical calculation is verifiable by actual experiments, as will be hereafter shown by various illustrations of conducting wires and magnets, reciprocally revolving about each other.

The wire, W, begins to move in obedience to a general law of arranging the conducting body in a similar direction with the current traversing the approximated side of the adjacent body; but by the peculiar mode of the suspension of the wire, this incipient effort is artificially frustrated every moment, as soon as developed, by resolving it into circular or tangential action; and a consequent continuous revolving movement about the N pole of this cylinder, representing the N pole of a magnet will take place.

If the wire were extended below the lower end of the cylinder, whilst suspended by the upper extremity, the oppositely-directed impulses indicated by the lateral arrows, W N, and S W, will prevent a continuous revolving movement. It is therefore necessary, in order to produce a continuous revolving movement by the reciprocal action of electric currents directed transversely to this electro-dynamic cylinder, or to magnets represented by this cylinder, to limit the action to *one end or pole only*, and then to withdraw the circuit of the current from the counteracting influence of the opposite pole.

If the conducting wire be terminated between the middle of the cylinder and the lower point, S W, it will be noticed that it recedes from the current about the lower edge of the cylinder. On referring to the electro-dynamic key, it will be found that these relative directions of movements correspond with No. 7, showing that the conducting wire should be moved in the same direction with the current, and in the same direction as the hands of a watch move about the dial-plate.

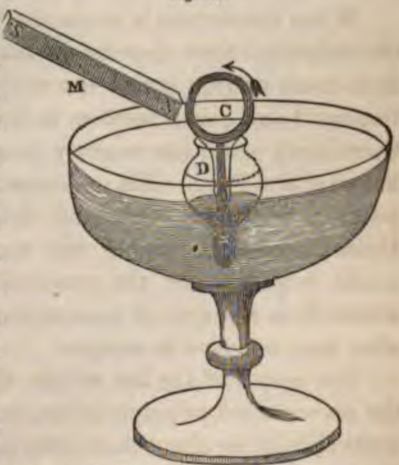
Thus it is theoretically demonstrable that considering this electro-dynamic cylinder to represent a magnet, a conducting wire similarly suspended over the north pole of a magnet, will continuously revolve in an *opposite* direction to the movements of the hands of a watch about the dial-plate; and that if this conducting wire be removed so as to allow the same current to move from the south pole of a magnet, that the wire will continuously revolve in the *same* direction as the hands of a watch move about the dial-plate.

The application of these rules will repeatedly occur in our future descriptions of the various kinds of electro-magnetic apparatus devised to produce continuous revolving movements of conducting bodies about the poles of magnets, and of magnets about conducting wires, and even about their own respective axes.

The opposite action propagated by these oppositely directed impulses on the upper end of the wire N W, and on the lower end S W, combine to turn it about crosswise of the cylinder, as presented by *w w*. In this particular relative position, the currents propagated through *w w*, and through the spirals nearest thereto, become arranged in similar directions.

Nor does this action end here; for if *w w* be nearer to one end, S, of the spiral cylinder, than to the other end, N, the excess of the multiplied circuits about the upper end will prevail over the comparatively less number of circuits about the lower end, and the wire *w w* will be moved laterally to the exact middle part of the cylinder, where it will finally remain at rest, or in a natural electro-static condition. For this same reason the wire *w w* will become finally arranged *precisely across the middle of a bar magnet*, if allowed freedom of motion. This is exhibited in the following beautiful illustration with a floating Ring of De La Rive, C, sustained by a little glass cup D, containing the usual appended plates and acid. On approaching the end of a magnet N, toward this Ring, and in a level position, the floating coil will sail toward it, and over it, as the eye of a needle is passed over a thread, stopping its movement only when it has arrived at the exact middle part of the bar.

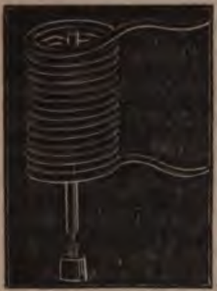
Fig. 37.



By inspecting the direction of the arrow about C, it will be perceived to indicate the circulation of a current in the opposite direction to that of the hands of a watch about the dial plate, which side is thus denoted to be endued with the characteristic properties of the N pole of a magnet. As the two similar N poles of magnets always repel each other, so if the N pole of a bar magnet be presented toward that particular side of C, the ring will sail away therefrom; but will immediately sail back if the opposite S pole of the magnet be presented thereto.

By no artificial arrangement of the parts of conducting bodies and magnets, can so comparatively great a surface of the circulating currents about each be brought to act and react on each other, as by environing magnets with the spiral coils of a conducting wire, or *Helix*, as represented in the annexed figure; for in this case the whole extent of the currents circulating about the outer circumference of the magnet is brought into proximity with the whole extent of the currents circulating about the interior of the coil. When a simple conducting wire is brought near the surface of a bar magnet, the action and reaction are confined to one point of proximity; but when its multiplied circuits lap around the entire cirumference of the magnet, then the greatest possible extent of action and reaction is rendered effective.

Fig. 28.



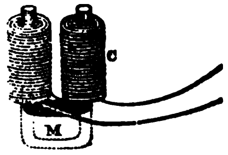
When the current is propagated through the coil, the impulses of mechanical force thereby developed are found to be so intense as to cause an iron bar of the weight of several hundred pounds to ascend and gain a position in the middle of the coils. This extraordinary result has recently been accomplished by the devoted labors of Dr. Page. His experiments are sustained by an appropriation of twenty thousand dollars by the Congress of the United States, for testing this mode of propagating electro-dynamic impulses, for the practical purpose of rendering them available as a source of natural motive power; as we shall hereafter have occasion to narrate.

The ascent of the bar within the spiral coils is ascribable to the above stated principle of action and reaction between the currents circulating about the circumference of the magnet, and about the interior spiral coils. If there be a greater number of circuits about the upper half of the bar than about the lower half, the reciprocal attraction induces its ascent, until an equal number of currents become arranged above the middle of the spiral coil as are arranged beneath it, when a condition of equilibrium ensues. Were the bar to be placed with one end projecting above the top of the coil, it would be similarly drawn down to the centre.

By this arrangement the two approximated bodies develope the most intense reciprocal electro-dynamic action and reaction on each other. Dr. Page, in adopting this plan of rendering electro-motive power the most efficiently available for practical purposes as a source of Natural Motive Power, has therefore selected the most efficient practicable method of arrangement. This important experiment, therefore, appears to be worthy of being thoroughly made at the national expense.

A similar principle of arrangement of two ends of an U magnet, is shown in the figure, where the bar is exhibited as drawn up from the dotted lines beneath, whilst the current is propagated about the coils C C. It falls back by gravity when the electric current is cut off. By quickly breaking the electric circuit a rapid vibration may be produced.

Fig. 39.



The preceding experiments are sufficient to establish the conviction of the truth of the principles which have been advanced, that all the phenomena of Attraction, Repulsion, and Polarity, are traceable to the propagation of electro-dynamic action about bodies in various relative directions, and that the phenomena of electro-dynamic action, and those of magnetic Attraction, Repulsion, and Polarity, are identical. The fact remains to be shown that the propagation of electro-dynamic action not only represents magnetic action, but is even adequate to establishing a circulation of electric currents in connection with iron and steel bars, &c., which converts them into magnets.

Whilst Ampère was pursuing experimental researches upon the action developed between bodies serving to propagate electric currents, another eminent French philosopher, Arago, and Davy, commenced experimenting upon the action of electric currents, upon other kinds of substances than those endued with magnetic properties.*

Arago began by holding the conducting wire connecting the poles of an excited battery close to some iron filings, which he found to rise up and encircle the wire in concentric rings. This experiment, when exhibited with the small nails, shows the result more strikingly, as exemplified in the figure. He thus made the exceedingly important discovery, that soft iron becomes endued with magnetic properties by the immediate presence of electricity in motion.

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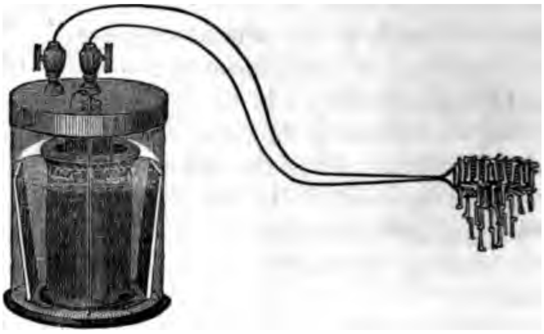
* The original account of some of these interesting experiments may be found in vol. xv. page 98, of the Annales de Chimie et de Physique.

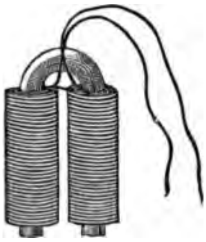
Fig. 40.



When the current was cut off, the filings fell off from the wire. This fact led to the conclusion, that soft iron is endued with only temporary magnetic properties, which become manifest and disappear with the commencement and termination of the approximated electric current.

When a conducting wire is wound in numerous spiral coils about a piece of soft iron, the latter is converted into a powerful electro-magnet. This plan was recently adopted by Professor Morse, in the United States, for developing the electromotive power employed in operating the mechanism of his telegraph.

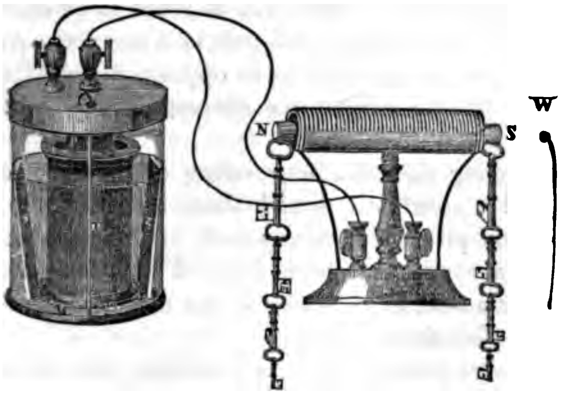
Fig. 41.



Subsequently, by placing pieces of steel in the spiral coils, as invented by Ampère, Arago found that they became endued with magnetic properties, not only temporarily, whilst the electric current was circulating in the spiral coils surrounding them, but also permanently.

This plan of exciting permanent steel magnetic needles and bar magnets is now commonly resorted to as a more effective and expeditious process of magnetizing such needles and bars, than the original plan of friction of magnets on steel needles or bars.

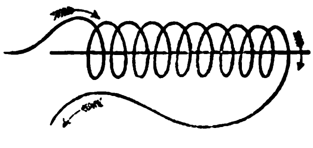
Fig. 42.



For more conveniently exhibiting this experiment, the spiral coils connected with a galvanic battery, as shown in the figure, are mounted on a stand, and the pieces of iron or steel to be magnetized are inserted therein, suitable connecting cups being arranged on the stand.

By means of propagating electro-dynamic action about the spirals, inclosing a sewing needle, as denoted in the figure 43, it has been found that a frictional electrical machine may be successfully employed for magnetizing it, instead of a galvanic battery; and that even a spark of the discharge of a jar is sufficient for this purpose. So instantaneously and delicately is this result produced, that it is resorted to as one of the most sensitive electroscopic tests, available for determining the fact whether electric action may have been propagated through a given circuit.

Fig. 43.

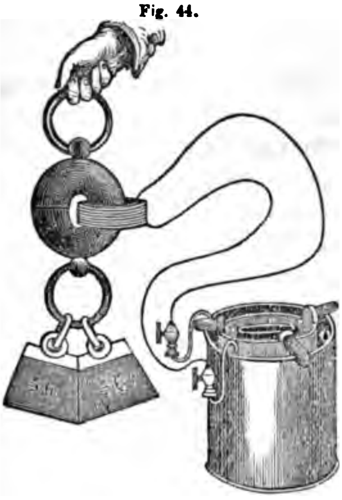


This magnetization of a steel needle not only serves as a test of the fact of electric action, but even of the *direction* in which the action may have been propagated through the environing spiral coils. It is only necessary to ascertain to which end of the needle may have been imparted the peculiar powers of an N pole.

If the action be propagated through the coil in the direction indicated by the arrows in the figure,—that is, if the current has traversed about the circuitous spiral coils in the direction in which the hands of a watch move about the dial-plate, that particular end at which the current enters will be found to be endued with the power of acting like the *south* pole of a magnet. And if, on the contrary, the current move in an opposite direction, the same end will be found to exhibit the characteristic properties of a *north* pole.

By connecting the metallic covering of the roof of a large building with a wire thus wound about a needle, the electro-dynamic action propagated from a flash of lightning at the distance of twenty miles, has been detected by Doctor Page. He considers that a flash of lightning at the distance of a hundred miles might affect the needle.

Fig. 44.



If electro-dynamic action be established in a circuit about atoms formed into rings, as of the two halves of an iron ring in the manner shown in the figure, by including the junction of the two ends within the spiral coils of a helix excited by a galvanic battery, a very intense development of attraction is produced between the conjoined semicircles of iron. This action becomes permanently established between the conjoined halves of the iron ring, continuing long after the connection with the exciting battery is cut off, with sufficient energy to sustain a considerable weight. This electro-dynamic union of a piece of iron represents the process of *welding*, and may be effected by substituting a thermo-electric battery in place of the galvanic battery exhibited in the figure. Thus the "cohesion" of the parts of an iron bar may be established alike by the propagation of mechanical action through the medium of electric matter excited by the recoil of the atoms of zinc in the galvanic battery, or of the fuel in a furnace, from their several constrained static conditions to their natural static conditions, as has been premised.

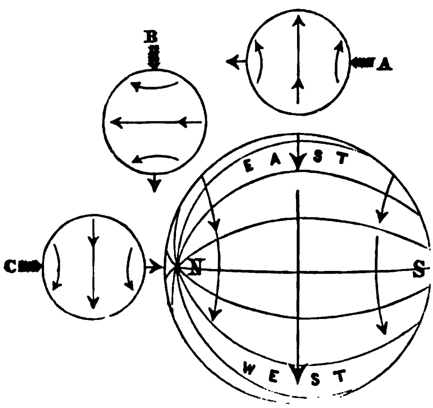
This peculiar final electro-static condition of the arrangement of iron within the spiral coils, as above described, may appear to be of an artificial character, and unlike the natural arrangements of groupings of atoms at insensible distances, and of masses at sensible distances, which are found naturally in the static conditions of the organic and inorganic formations that have been adverted to in the preceding pages.

But although there are found in nature no bodies exhibiting hollow arrangements, one with another, like those of helix coils inclosing magnetized bars, yet it is to be considered that every solid body is composed of successive series of atoms constituting circles, one inclosed within another, in successive layers. All solid bodies may therefore be considered as constituted of a series of such combined helix coils, or circles, brought within the most intimate influence possible of each other's reciprocal actions and reactions. The most energetic propagation of electro-dynamic action might be theoretically anticipated from this compact arrangement of atoms into circuits adapted to *polarizing* the masses composed thereof. This subject will hereafter be reverted to when we come to treat of COHESION.

The propagation of electro-dynamic action about atoms and masses of matter produce two decided natural static conditions of their relative arrangements, as has just been shown, viz.—An arrangement of atoms and masses with their *equatorial* currents moving in similar directions and facing each other, as in the two Rings, figure 23, and with their *polar* currents facing each other, as between A and B, figure 22.

The former is an unstable equilibrium of counterbalanced forces;—the latter a final static condition of them. The former represents the condition of a dipping needle whilst remaining balanced horizontally in the equatorial regions of the earth; the latter the vertical position of the same needle, at the magnetic pole of the earth. At the Arctic pole, the N pole of the needle becomes turned entirely about, or reversed, as shown by the following diagram, pointing *from* the north star, instead of pointing toward it. The terrestrial electric currents may be represented by the arrows directed from East to West about the spherical body N S, and the currents about magnets, or spherical atoms and masses of matter, by the arrows about A B C. The intermediate position of the needle or body at B represents the half-turned arrangement of the *dipping needle.*

Fig. 45.



In the equatorial arrangement of a needle, shown at A, only arcs of the currents act and react on each other. In the polar arrangement they present toward each other entire circles. The predominant action of polar arrangements of magnets over equatorial arrangements becomes thus manifest by the greater extent of acting and reacting approximated currents.

The terrestrial electric currents are found to circulate nearly about the axis of the earth; and there is reason to believe that the same law prevails in the arrangement of the currents about the respective axes of the other planets. As they all present toward each other nearly their equatorial parts, as represented by A and N S, it follows that they are arranged in the constrained static condition, denoted also by figure 23, rather than in a polar condition, represented by C and N S. In the latter position they would be most powerfully urged toward each other; in the former position they may be considered, as it were, purposely placed with reference to perpetuating their continuous revolutions at a distance, rather than for producing a tendency to a final static condition of approximation and rest, as the theory of universal gravitation, without this modification, would lead us to infer. The attraction between the planets, therefore, represents a minor intensity of electro-dynamic action.

Were all the planets of the solar system arranged in the space of the heavens with their repective polar currents facing each other, a more intense direct attraction or repulsion would ensue, accordingly as the currents about their approximated poles might circulate in similar or dissimilar directions.

The electro-dynamic action between similarly directed equatorial currents circulating about the axis of atoms of matter at insensible distances, as well as between masses at sensible distances, also represents a minor power of attraction as compared with the electro-dynamic action that ensues between the respective similarly-directed polar currents. And hence it may be theoretically anticipated, that bodies composed of aggregations of atoms held fast together by this equatorial mode of reciprocal electro-dynamic action may be cleaved more easily in the equatorial direction, than in the opposite polar direction.

This difference of the relative arrangements of equatorial and polar currents about atoms at insensible distances, furnishes a solution of the problem of the *cleavage of the faces of symmetrical crystals*, in successive layers down to the very nucleus. And as the preceding calculations show that a dynamic action may occur between the centres of electro-polarized bodies in every direction relatively to their several approximated poles, as exhibited between A, B, C, and N S, the symmetrical arrangements of atoms into various shapes of angular or polygonal crystals may be accounted for by the laws of electro-dynamic science, the different angles coinciding with the variation of the dip of the dipping needle when transposed to different parts of the earth's surface.

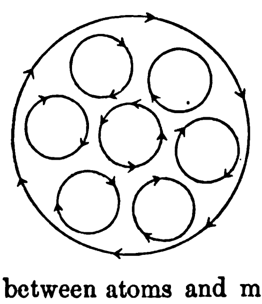
But although the polar arrangement of bodies may be their final electro-static condition, yet they are retained from readily changing from their constrained equatorial arrangement by powerful electro-dynamic reaction. The dipping needle recovers its horizontal position when forcibly inverted on one end at the earth's equator, as it recovers its vertical position at the magnetic pole of the earth, when it is there forcibly turned to a horizontal position, on the preceding principle of attraction between similarly directed currents. If the end of a needle be inverted at the equator, it is manifest that on one side of the needle the currents must necessarily move about its axis in an opposite direction to the terrestrial currents, and in the other part of their circuit they must move in similar directions. The consequent attraction on one side and repulsion on the other, will tilt back the needle from a dipping or vertical inclination at the equator.

By applying the same reasoning to demonstrate theoretically the electro-dynamic action that takes place at the magnetic poles of the earth, it is manifest that if the terrestrial electric currents represent simply actual currents flowing from east to west about the earth's surface, that the needle should become arranged horizontally at all parts of the earth's surface, as well as at the equator; because a section of the circle of currents about the axis of the earth bears nearly the relation of a straight line to the minute circle about the axis of a magnetic needle. The curvature of the surface about the axis is only eight inches to one mile at the equator, and probably about as many feet at the magnetic pole attained by Captain Ross.

For this reason it becomes necessary to revert to the fact, that terrestrial magnetism, like that of a bar of steel, is not constituted simply of a general system of circular currents about its axis, but is rather the resultant action of a general electro-polarization of all the atoms of the mass.

It is familiarly known that every particle of the matter of a steel bar magnet, however finely it may be pulverized, is a perfect magnet in itself. Its atomic powers become merged in the general action of the mass. This idea was illustrated by Ampère, by "supposing a magnet of cylindrical shape to be constituted of numerous component filaments, around each of which electric currents are circulating continuously in one common direction, as illustrated in the figure by the arrow heads; their conjoint action being equivalent to that of a single circular current, propagated in an uniform direction about the circumscribing circle. Hence in estimating the action of all the parts, the resultant external action of the whole may be alone regarded."

Fig. 46.



These investigations of reciprocal electro-dynamic actions and reactions between atoms and masses at sensible and insensible distances will presently be resumed after completing a synthetical view of the rudimentary facts of the science of electro-dynamics.

Considering the universally diffused electric matter to be a perfectly mobile fluid, and that it is actually in motion about the surface of the whole mass of the earth, as tested by the preceding electroscopic instruments—such as compass needles, and wire coils serving as conductors, the conclusion appears to be certain, that this general disturbance of the whole must induce a disturbance of the electric matter environing every atom of the mass. And as every movement of electric matter, as well as of grosser matter, serves to propagate electro-mechanical impulses between bodies, we are now prepared to comprehend the existence of an adequate cause, not only of the continuous propagation of impulses, but also of their varied directions, producing the effects of attraction, repulsion, and polarity, or rather of an *universal polarization of all matter.*

It is for the special purpose of establishing this fact as a general fundamental law of the Science of the Mechanics of Nature, that the preceding details have been preliminarily considered. The unequivocal recognition of this truth is absolutely necessary to a right comprehension of the existence of modifying causes producing all the relative states of rest and motion of matter. Otherwise we should be compelled to commence the study of this branch of science with the usual ascription of the phenomena of Attraction, Repulsion, and Polarity, to "inherent" and "innate" self-motive and self-directive forces, in violation of the laws of mechanical science establishing that matter at rest cannot put itself in motion, or turn aside from a straight course.

Minute and insignificant as may appear these slight changes of the directions of almost undiscoverable impulses of electro-dynamic actions and reactions as applicable to elementary atoms at insensible distances, yet it is to be ever remembered, that the motive power which controls the states of rest and motion of every atom, must control the states of rest and motion of all masses of matter.

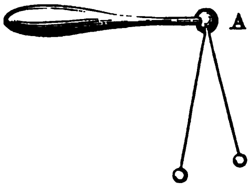
The very aggregations and consolidations of atoms into visible magnitudes, it has been shown, are due to this same cause of natural electro-dynamic power, propagated in the modified form of Polarization.

All the various natural states of the relative motion and rest of the several different kinds of elementary atoms in the processes of chemical attraction and repulsions,—of crystallization, and of magnetism, present so many analagous evidences of originating from this law of the excitation and action of electric matter in accordance with the preceding facts of POLARIZATION, that an intrinsic importance becomes attached to these primary principles of the science of electro-dynamics.

Indeed, without these preliminary investigations, it would be impossible to attempt to offer any rational explanation of the real nature of the primary electroscopic tests of the pith balls, which have been always heretofore introduced as the main test of the normal principles of the science of electro-dynamics.

The attempt to explain the cause of this separation of the pith balls of electroscopes, used as tests of electric excitation, has been purposely reserved as the last and most difficult problem in the science of electro-dynamics. Although the little instrument represented by the annexed wood cut is always held up before the eyes of the student in the lecture room, and its diverging balls are pointed to as standard tests of electric excitation, yet the tracing out of the mechanical cause of this mechanical effect appears to have been either disregarded as of little importance, or studiously precluded by ascribing the movements of the balls, as before stated, to "inherent" forces, innate in matter.

Fig. 47.



Mechanical science teaches us that electric matter, like all other matter, must receive impulses before it can propagate them; that a portion of passive matter must be moved by some cause extraneous to itself, before it can produce movements of other portions of matter.

When pith balls are suspended from the main conductor of an electrical machine at rest, they remain quietly drooping side by side. If the hand be applied to turn the crank-handle to propagate the mechanical action of the animal motive power to move the parts of the machine, we discover that the balls become divergent as instantaneously, as if the fingers were applied immediately to separate them. This separation certainly cannot be ascribed to inherent self-originating motive power either in the pith balls or in the electric matter, because it is contingent on the propagation of the animal motive power applied to the crank-handle. It cannot even be ascribed to self-originating inherent motive power of the animal mechanism; for animal motive power has been shown to be contingent on the combustion, in the lungs, of food produced by the electro-dynamic action of the sun. Hence the diverging of the pith balls is thus intermediately traceable to the propagation of mechanical action originating from the electro-dynamic action of the sun on the organs of plants. The same observation applies if steam power or wind and water power be employed, which are alike contingent on solar excitation, as has been repeatedly stated.

The matter of the main conductor of the electrical machine, and of a far extended insulated conducting wire (if the pith balls be suspended from the extreme end thereof), remain unmoved after the motive power is applied to turn the electrical machine to excite electricity. The balls are moved asunder independently of the visible movement of intervening matter. This fact leads to the inference, that the mechanical action is propagated from the hand through the medium of the invisible electric matter existing in connection with the passive matter of the parts of the machine and connecting wire.

This fact being admitted, it remains now only to retrace our steps, to ascertain how bodies are caused to move toward and from each other by impulses of mechanical action propagated through the medium of electric matter.

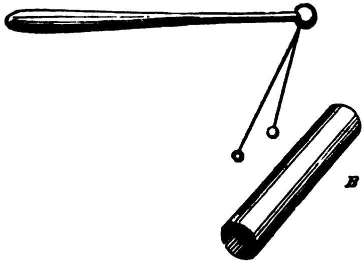
The preceding examples have practically established the truth of the fact, that the propagation of impulses through the medium of electric matter in dissimilar directions about the surfaces of approximated bodies,—that is, the *opposite polarization* of bodies, will cause them to move asunder. We therefore conclude that the impulses imparted to the pith balls through the medium of electric matter excited by an electrical machine, must have induced a propagation of electro-dynamic action about the approximated sides of such balls in dissimilar directions.

An exact imitation of the phenomena of attraction and repulsion, exhibited by the pith balls of electroscopes, may be produced by winding a fine coated conducting wire in numerous spiral coils about any spherical body, to represent this polarization. The two ends of the conducting wire wound around each ball are to be extended to represent the thread by which each pith ball is suspended, the ends being bended over like a hook, with the inverted points resting severally in two distinct mercury cups, constituting the two poles of a galvanic battery. The phenomena of the continuous divergency or convergency, representing repulsion and attraction, are at pleasure producible by reversing the directions of the currents. This is simply another form of the experiment with the swinging wires of the frame shown at page 220, figure 20, which is similarly polarized by the propagation of electric currents.

The two similar poles of polarized bodies, like two magnets, for instance, repel each other, for the reason illustrated by the approximated floating rings, B *a*, figure 22, the currents being propagated in opposite directions about the sides facing each other. But it appears that all bodies, not even excepting the loadstone and tempered steel-bar magnets, have a mutable polarization, determinable by the approximation of other more highly excited portions of matter.

When the pith balls of an electroscope are brought into contact with a tube of glass, a stick of sealing-wax, or other body, B, previously subjected to friction, they all become reciprocally repelled from each other as shown in the figure, if the body B be electrically excited.

Fig. 48.

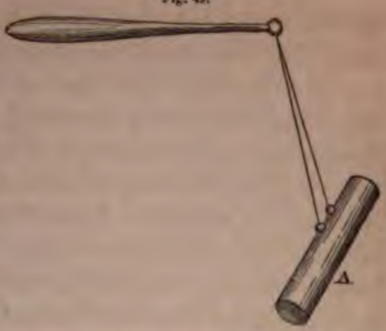


The same result of reciprocal repulsion occurs when the same operation is repeated with the electroscope upon the body which has been used as a rubber.

But if the balls, after being rendered divergent by contact with the rubber, be brought near the rubbed body, they will be urged toward it, as shown at A, figure 49. In contact they will droop, as if the forces were neutralized; and the next moment they will acquire an opposite polarization and reciprocally repel each other, as in the first instance.

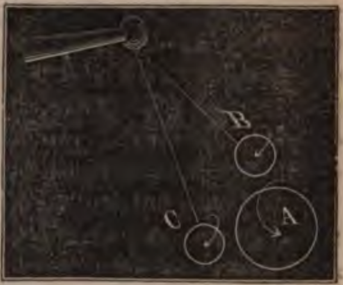
These different opposite movements indicate simply a change of directions of impulses of mechanical force, which have been

Fig. 49.



previously shown to be incident on every change of the direction of electric currents circulating about the approximated sides of bodies. These changes constitute reversals of the polarization of atoms or masses.

Fig. 50.



The similarly directed circuits denoted by the arrows about the excited body A, and the pith balls B C, show that attraction may take place between A and the pith balls, as will actually occur when they are brought into intimate contact by pressure thereon; whilst at the same time the opposite directions of the currents about each one of the pith balls indicate the repulsive action, which produces their reciprocal divergency.

When the pith balls are urged to adhere to the surface of an excited body, after being pressed thereon, as has been previously stated, a new order of polarization, or of the direction of the electric action becomes induced about the circumference of the conjoined bodies, embracing them in one entire electro-dynamic circuit, and producing a new arrangement of polarity of the grouping of the conjoined atoms or masses.

Instead, therefore, of ascribing the phenomena of Attraction and Repulsion, which we perceive to take place between insulated excited bodies, to the inherent self-originating and self-motive power of "Two kinds of Electricity," as supposed by Dufay, or to a similar self-motive power innate not only in "one kind of electricity," but also in all kinds of matter, as affirmed by the Franklinian theory, it may rather be inferred that the phenomenon of the continuous divergency of the pith balls of electroscopes may really be due to the continuous propagation of mechanical action about the circumference of masses of atoms in the modified form of oppositely directed electric currents, and of consequently opposite polarizations.

The due establishment of the principles of mechanical action and reaction between a pair of pith balls used as electroscopes, before proceeding to treat of the phenomena adjudged thereby, also leads us to another exceedingly important explanation of the mystery of simultaneous appearances of two oppositely directed electrical forces, or of two opposite kinds of electricities, and of "the impossibility of separating these two forces or electricities from each other," as stated in the words of Professor Faraday.

Mechanical science has established the law, that *there cannot take place the action of one body on another, without the simultaneous development of an exactly opposite and equal reaction.*

The opposite mechanical impulses, propagated through the medium of electric matter to the gross matter of all rubbing and rubbed bodies, exhibit sufficiently palpable evidence of the truth of this law; and it only becomes necessary to extend the application of it to account for the inseparable appearance of two oppositely directed electric forces.

If electric ether be matter, or a material medium, it must be subjected to the same mechanical laws as all other matter; and whilst the surfaces of the rubbing and rubbed bodies are brought to act on each other, the portions of electrical matter existing in connection with their respective surfaces must similarly act and react on each other. The electric matter being a perfectly mobile fluid, it must consequently be as impossible to put a portion of it in motion in the form of currents in one direction, without simultaneously putting an exactly equal portion of it in motion in an opposite direction, as it is to put a cannon ball in motion in one direction without imparting an exactly equal momentum to the mass of the cannon in a precisely opposite direction.

The two opposite forces developed in all cases of electrical excitation, on this principle, may therefore be ascribed to the simple law of MECHANICAL ACTION AND REACTION between portions of electric matter.

A further pursuance of this inquiry for the present, will be suspended, until other facts of the modes of excitation and propagation of electro-dynamic action have been investigated. With the establishment of the preceding principles of the propagation of mechanical impulses through the medium of electric matter to serve as a chart to guide our course, we may be better prepared to recommence tracing out to their originating source the mechanical causes of Natural Motive Power.

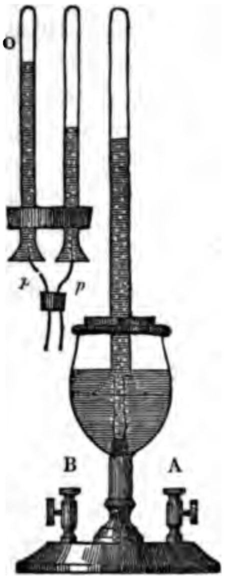
The reciprocal repulsion of atoms at insensible distances, denominated, "Expansion by Heat," which is practically resorted to in the common use of the THERMOMETER as a test of the phenomena of Heat, will hereafter be considered as embraced under the above stated general laws of Electro-Polarization.

THE POLARIZATION OF ATOMS AT INSENSIBLE DISTANCES, AND THEIR CONSEQUENT RECIPROCAL ATTRACTIONS AND REPULSIONS, (DENOMINATED CHEMICAL COMPOSITIONS AND DECOMPOSITIONS,) CONSIDERED AS TESTS OF ELECTRIC EXCITATION.

Atoms of oxygen and hydrogen are united together at insensible distances to constitute the compound substance of water. The separation of these substances, atom by atom, is effected by dipping therein the two opposite ends of the conducting wires of battery circuits. This process was often resorted to as an electroscopic test of the propagation of electro-dynamic action before the discovery of the action of electric currents on the needle of the galvanometer. When bubbles of air were seen to arise from the ends of the conducting wires, it was concluded that the water was decomposed by the propagation of the electro-dynamic action through it.

In order to collect and measure the quantity of gas rising in bubbles to the surface of the water, it is usual to employ a glass vessel or tube, inverted over the two approximated ends of the wires. This combined arrangement of a receiver over the two points of conducting wires employed for propagating the electro-dynamic action, has received the name of VOLTAMETER, or *measurer* of "*voltaic electricity.*"

Fig. 51.



In the annexed wood-cut is represented the apparatus which is usually employed for exhibiting in lecture-rooms the effects of chemical decompositions producible by electric agency. A glass cup is mounted on a stand having two platinum wires inserted through the supporting stem, one united with the connecting screw cup, A, the other with B. The electric current transmitted from a battery may thus pass up one of the platinum wires, and from thence through the water to the opposite wire and back to the battery. The metal platinum is selected as being the least subject to become chemically united with the oxygen; in which case the oxygen, instead of being set free in bubbles, becomes solidly fixed in the form of a metallic rust.

The cup being filled with acidulated water, as shown in the figure, whilst the screw e connected with the battery, bubbles of gas will be seen to escape from each wire, and to rise to the surface of the water.

To collect the gas, a glass tube, G, may be inverted over these wires, and supported by a tight cover fitted to the rim of the cup. By inverting this cup, the glass tube becomes filled with the water, which remains suspended in the tube after it is restored to a perpendicular position. The bubbles of gas rise up in the tube, and occupy the upper portions thereof, where they become collected, and displace the water, as depicted in the figure.

The mixed gases which fill this tube, when kindled by an electric spark, or by the flame of a lamp held under its mouth after being withdrawn from the cup of water, will explode. They recoil to their natural static conditions of pure water, propagating electro-dynamic action in the form of heat, and light, and violent impulses of mechanical force exerted against surrounding bodies.

To obtain the two gases in a separate state, it is only necessary to employ two glass tubes, O, H, instead of one, severally arranged above the ends of the two wires, when the bubbles arising from the respective ends of each of them will enter the bell-shaped orifices of the separate tubes.

By this experiment it is uniformly found that the atoms of the oxygen gas are collected in the tube over the wire that *delivers* the electric current in its passage from the battery or other excited body; whilst the hydrogen, constituting the other elementary ingredient of water, is found to be always collected in the tube placed over the wire that *receives* the current and transmits it back to the battery. The former wire is denominated the *positive*, and the latter the *negative* pole of the battery circuit.

In this process of the electrical decomposition of water, the volume of oxygen gas collected in the tube over the positive wire, is found to be only about half of the volume of the hydrogen gas, as indicated in the figure by the relative heights of the liquids in the tubes, O and H. These tubes being marked off into equally graduated spaces, serve respectively to measure the volumes of the two gases reduced from their natural static condition of water, to the constrained static condition of distinct collections of atoms of hydrogen and oxygen gases.

Whilst passing in review the Voltameter, considered in its alleged character of performing the functions of determining the *quantity of electricity* passed through it, as its name implies, it should be here noticed, that it would mislead the student to employ this instrument, without duly appreciating the phenomenon of the decomposition of water thereby produced, and considered as a standard test of the absolute quantity of electric matter employed to accomplish this specific result.

The Voltameter considered as a Standard Test employed for measuring a quantity of Electricity.

In treating of the minuteness of atoms of matter, it has been demonstrated, that all our knowledge of the existence of matter depends on the grouping together of numbers of atoms constituting a mass of sufficient magnitude and stability to become appreciable by the powers of human perception, or to be weighed in balances. But as electric matter, considered as an universally diffused fluid medium, occupying all space, cannot be subject to the otherwise universal laws of gravitation, it is manifest that it can never be in the power of man, with his present endowments of material nerves of perceptions, to ascertain the ABSOLUTE QUANTITY OF ELECTRIC MATTER employed in any way to propagate electro-dynamic impulses between atoms and masses of terrestrial matter.

Mr. Faraday, the most eminently distinguished experimentalist and discoverer in this branch of science, instituted experiments with a view to ascertain the absolute quantity of electricity existing naturally in connection with the elementary atoms of matter. In order to arrive at this result, he founded his calculations on the fact of setting free from the united atoms of various compound bodies the share of electricity that naturally exists among them, and holds them united together *chemically*, as it is termed. He considered that "if the electrical power, which holds the elements of a grain of water in combination, or which causes a grain of oxygen and hydrogen, in the right proportions, to unite into water when they are made to combine, could be thrown into the condition of a *current*, it would actually equal the current required for the separation of that grain of water into its elements again." Acting on this principle, he caused the electro-dynamic action propagated from a galvanic battery to issue from the end of a wire connected therewith, and to pass through a quantity of the atoms of the compound substance of the water to be decomposed, and then to enter the end of another wire to complete the circuit to the battery. Faraday considers, "that if a given definite quantity of electricity passed, an equal definite and constant quantity of water or other matter is decomposed; and also that the agent, which is electricity, is simply employed in overcoming electrical powers in the body subjected to its action; and that it is a probable, and almost a natural consequence, that the quantity which passes is the *equivalent* of, and therefore equal to, that of the particles separated."

After witnessing the result of this experiment, he exclaims, "It is wonderful to observe how small a quantity of a compound body is decomposed by a considerable *quantity* of electricity; for *one grain* of water (acidulated to facilitate its conducting powers) will require an electric current to be continued during $3\frac{3}{4}$ minutes to effect its decomposition, which current must be powerful enough to maintain, in a red hot state, a platina wire $\frac{1}{104}$ of an inch in diameter, and of an indeterminate length, exposed to the air during all this time." "It is not too much to say that *this quantity of electricity is equal to a very powerful flash of lightning.*"

He has supposed from other comparative experimental investigations that "800,000 charges of a powerful Leyden battery would be necessary to supply electricity sufficient to decompose this single grain of water; or to equal the quantity of electricity which is naturally associated with the elements of that grain of water, endowing them with their mutual chemical affinity."

Although electro-dynamic impulses are manifestly propagated continuously between an insulated rubber and main conductor of the frictional electrical machine, and between the zinc and copper plates, yet all our knowledge of these impulses is confined to the facts of the development of mechanical action through the medium of electric matter. We are not yet furnished with any sufficient data for deciding whether this mechanical action be propagated by vibrations of the perfectly mobile electric matter, like that of the air in propagating sounds—by principles of an hydrostatic pressure, like that of water confined in pipes—by the continuous repetitions of the circulations of the same specific quantity of electric matter in reiterated currents,—or by variously combined modifications of all these modes of propagating more or less energetic electro-mechanical impulses.

With the velocity of the propagation of electro-dynamic impulses at the rate of about 200,000 miles per second, the repetitions of such electro-dynamic impulses admit of being multiplied many billions of times through the short circuits of conducting wires by means of the same quantity of electricity.

An inconceivable number of reiterated impulses must be propagated between the two plates of a galvanic battery, and between the rubber of a main conductor of an electrical machine, with this velocity of the propagation of mechanical action through the medium of electric matter during 3¾ minutes.

A small quantity of electric matter may serve continuously to propagate electro-dynamic action during the whole period of the 3¾ minutes of time. In decomposing water by the use of the magneto-electric machine, which will be presently described, the fact is demonstrable, that about 24,000 repetitions of tidal waves of the *same quantity* of electric matter, existing in connection with the helix coils, may be propagated through the mechanism of a "current changer" in one minute, which would give nearly 90,000 impulses in 3¾ minutes, to produce the decomposition of one grain of water in the voltameter, as stated by Professor Faraday.

The decomposition or separation of the atoms of water being a mechanical effect produced, there appears to be no more reason for considering the production of this specific effect as a test of the quantity of electricity employed to produce it, than the production of the specific effect of lifting a weight of 1000 tons, as a test of the quantity of matter put in motion to lift it. A gallon of water in an hydraulic press may be adequate to propagating a mechanical action sufficient to accomplish this result.

The extent of mechanical action, not of the quantity of matter employed, is determined by the test of the decomposition of water in the voltameter. Hence, the idea of using the voltameter as a test of the quantity of electricity employed appears to be fallacious.

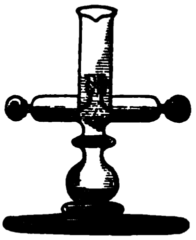
As electric matter is an universally diffused medium, it must ever remain imponderable, for the reasons which have been stated. And as this matter does not impart movements to grosser matter by its momentum, there appears to be no imaginable mode by which human intelligence will ever succeed in detecting, or measuring, specific quantities of electricity.

Changes of Color considered as Tests of Electric Action.

The phenomenon of the chemical decomposition of various compound substances is also resorted to as a sensitively delicate test of the presence of minute electric currents. It has been found experimentally, that a certain compound substance, termed the *iodide of potassium*, is decomposable with great facility by the electro-chemical action of an exceedingly feeble current; and when a solution of this compound substance, instead of water, is placed in the above described instrument, one of the component substances, potash, appears developed at one of the poles, and iodine at the other.

It being known also, experimentally, that the presence of iodine in a solution of common starch produces an intensely blue color, recourse has been had to commingling a little starch with the solution of the iodide of potassium. By this means, the deposition of the least portion of the liberated iodine at one of the poles, which would not otherwise have been perceptible, becomes readily detectable *by the change of the starch to a blue color* at the surface of the battery wire immersed therein.

Fig. 52.



An improved form of this instrument is exhibited by the annexed figure; where the flattened extremities of two platinum wires are brought parallel to one another in a glass tube, as shown in the figure. So delicately sensitive is this instrument, that merely by dipping in acids the end of a wire composed of the metal zinc, connected with one of the platinum wires of this apparatus, and the end of another similar wire connected with the other platinum wire, so as to form a regular circuit through the solution of starch and iodide of potassium, a deposition will be discovered of a *purple hue.*

A few turns of a small electrical machine will prove sufficient to propagate electro-dynamic action to the platinum plates, through conducting wires connected with the two opposite knobs; as will also the heat of the tip of the finger applied to the junction of a wire of silver and of platinum connected therewith.

By connecting the poles of a thermo-electrical apparatus composed of a number of conjoined wires, presently to be described, with this instrument, the mere approach of a person near this apparatus will disturb its electro-static condition sufficiently to propagate an electro-dynamic action to the plates of platinum, whereby the blue color will be caused to appear. Even the animal heat of insects has thus been detected by Melloni to be adequate to propagating electro-dynamic action.

Instead of the iodide of potassium, Mr. Bain has adopted the use of ferro-cyanide of potassium to become decomposed for producing discolorations or stains on the prepared paper used for recording the characters of his "Electro-chemical Telegraph." He has practically introduced the new art of *electro-dyeing.* The atoms of iron of the point of the battery-wire are transferred to unite with those of the compound salt with which the paper is impregnated

The preceding facts will be sufficient to afford a synthetical view of some of the most important standard tests of the propagation of mechanical action through the medium of electric matter. With the aid of these landmarks to direct our researches, we may be prepared to adventure forth to trace out the causes of Natural Motive Power.

DYNAMICS.

"The primary object of science is to ascertain the cause which moves atoms, and the mode in which it produces so many diversified effects."

The movements of matter are appropriately considered under the branch of the science of mechanics denominated DYNAMICS. The propagation of force or power to move matter at rest, or to vary its state of motion in any way from a uniform movement in a straight line, is denominated Mechanical Action.

From what has just been premised of the propagation of mechanical action through the medium of electric matter, it will be readily comprehended, that the *Static* conditions of terrestrial matter are consequent on the universal system of Polarization of atoms and masses; and that its *Dynamic* conditions are consequent on changes of Polarization of atoms and masses.

Similarly directed currents about the approximated sides of portions of matter, have been shown to produce their final state of rest, or STATIC condition. Before proceeding to investigate the Dynamic conditions of matter, it is necessary to establish a clear comprehension of the meaning of the term "Static;" as the idea of the state of rest of matter is commonly considered to imply a state of rest or cessation of mechanical impulses. So far is this idea from being correct in the science of mechanics, that a true Static condition of portions of matter implies the action of at least two oppositely directed and exactly equal impulses. To produce a relative state of rest of bodies requires, therefore, the development of double the extent of impulses. When a stone is left to fall freely through the atmosphere, the gravitating impulses produce a continuously increased rapidity of motion. When the same stone is in a state of rest, or static condition, on the earth's surface, it still continues to be unceasingly urged by the same intensity of dynamic action as when left to fall freely through the air; but its further movement is arrested by an exactly equal and opposite reaction, which counterbalances the action. The stone at rest is therefore subjected to a double extent of dynamic action to which it is subjected when in rapid motion during its fall to the earth.

Thus a *static* condition, or relative state of rest of all atoms and masses of terrestrial matter, implies a double extent of the continuous propagation of exactly equal and opposite impulses, which counterbalance each other. In case of any disturbance of one of these counterbalanced impulses, either the resultant dynamic action, or the reaction, becomes paramount, and motion of the matter thus affected must ensue accordingly as the one force or the other may prevail.

On every disturbance of the *static* conditions of groupings of atoms at insensible distances, *dynamic* action ensues, as has been previously stated. In every development of Dynamic action, we are taught to look to an antecedent Static condition of counterbalanced antagonistic actions and reactions between approximated portions of matter. Indeed, all our knowledge of matter is based on the continuous propagation of mechanical action between atoms, producing their aggregations into magnitudes sufficiently great to become discoverable objects, and recognizable by human powers of perceptions, as has been recapitulated at page 21. Sir Isaac Newton commenced his consideration of the existence of matter, as "an *aggregation of the smallest parts,* which are material, and extended, and by an *unknown power* are strongly connected with each other."

In the preceding facts of Electro-Polarization, there has been shown to be developed a power adequate strongly and continuously to connect atoms with each other, and also strongly and continuously to hold them asunder, as in the phenomenon of crystallization, and of vapor of water in the sky.

By simply varying the directions of the propagation of electro-dynamic action about portions of matter, that is, by varying their Polarizations, it has been demonstrated in the Electro-dynamic Key, page 285, that there are producible all the various relative movements and states of rest,—of the Dynamic and Static conditions of terrestrial matter.

If all our knowledge of matter be confined to its powers, as affirmed by Faraday, and all the powers of matter be traceable to modified states of Polarizations of atoms at insensible distances, and of masses at sensible distances, then all our knowledge of matter is confined to its Polarizations. The characteristic properties of the different kinds of elementary matter must consequently depend on the differences of their respective powers in modifying the propagation of electro-dynamic action, constituting their respective Polarizations.

The endowment of specific powers of modifying the propagation of electro-dynamic action has been traced (page 71) to the groupings of specific portions of atoms into molecules representing the sixty simple elementary substances, and into organic mechanisms, each endowed by the First Cause with peculiar grades of powers of modifying the intensity and the directions of the electro-dynamic action continuously propagated from a source ninety-five millions of miles distant from the earth. Thus groupings of atoms into the molecules of the sixty simple elementary substances, and into the organs of plants, have been considered as constituting real mechanisms, specially designed and ordained for modifying the Polarizations of all terrestrial matter, producing the resultant static conditions of Inorganic and Organic formations, which have been described in detail.

The power of modifying the propagation of the electro-dynamic action of the sun developed by molecules of the sixty simple elementary substances in producing the phenomena of Polarization, has been denominated *Inorganic action.* The same power developed by groupings of atoms into innumerable mechanisms of the organs of plants (which produce the various polarizations of the constituent elements of carbonic acid gas and water into organic formations of fuel and food), has been denominated *Organic action.* By the term *Inorganic* action, we shall hereafter represent the polarizations produced by the grouping of atoms into molecules of the sixty simple elementary substances, as constituting so many distinct kinds of mechanisms; and by the term *Organic* action, we shall represent the polarizations produced by the groupings of atoms into the mechanism of living organic formations.

These Inorganic and Organic mechanisms have been shown to propagate forces and to perform functions antagonistically to each other; the latter, when paramount, producing Polarizations of atoms of carbonic acid gas and water, in the constrained static conditions of fuel, food, &c., from which the former, when allowed to become paramount, reproduce polarizations of these compounds, restoring them to their natural static conditions of carbonic acid gas and water. The resultant electro-dynamic action is exhibited in the modified forms of fermentation, combustion, &c., as has been recapitulated. On the facts of the reciprocal action and reaction of these antagonistic Inorganic and Organic actions, the two grand subdivisions of Inorganic and Organic chemistry are essentially based.

In treating of the DYNAMICS of the Mechanics of Nature, we shall adopt the same classification, by tracing out first, the forces and functions developed by the groupings of atoms into the lifeless molecules of the sixty elementary substances, considered as so many mechanisms adapted to propagating mechanical action through the medium of electric matter, in the modified form of Polarizations; and then of the forces and functions developed by the groupings of atoms into living mechanisms of organic formations of plants and animals.

With these brief preliminary explanations, we are prepared to commence tracing out the Polarization of molecules and masses at sensible and insensible distances, and the consequent propagation of mechanical action through the medium of electric matter.

INORGANIC ACTION.

In the preceding account of the groupings of atoms into Inorganic and Organic Formations, it has appeared that neither lifeless nor living bodies are endued by the First Cause with the absolute power of originating impulses of mechanical for

They are simply capable of modifying the directions of the impulses propagated to them from an originating cause external to themselves. Electric matter, like all other matter, in accordance with the laws of mechanical science, cannot be supposed to be endued with the power to move itself. It must be urged to move, in order to propagate action.

Considering every atom, as well as mass of atoms, to be surrounded by an atmosphere of perfectly mobile electric matter, it follows as a consequence, that every movement of one portion of matter near another must produce disturbances of the electric matter existing in connection with both bodies. In accordance with the law which has been previously stated, every disturbance of the relative states of rest of portions of matter produces a resultant propagation of electro-dynamic action, and the consequent development of mechanical impulses between the centres of such approximated portions of matter which have been denoted by the term Polarization.

The primary cause which moves atoms and masses,—not the secondary cause of the propagation of the impulses, is to be steadfastly kept in view, as the true originating source of the development of electro-motive power, and electro-polarization. In the operation of the frictional electrical machines and magneto-electrical machines, in which the relative movements of the parts are relied upon for exciting electricity, the motive power, applied to put these machines in motion, is commonly available from the human hand applied to turning a crank. This peculiar mode of propagation of impulses is derived from the combustion of organic formations of food in the lungs; and is a consequence of the recoil of the Inorganic reaction.

Hence, in every case of the excitation of electricity by the animal power of human beings applied to moving one portion of matter near another, we trace the originating mechanical cause of the motive power to a source 95 millions of miles distant. And in the case of the application of steam power, water power, and wind power, to turning magneto-electrical machines, a similar view must be taken of the originating mechanical source of the electro-excitation, as has been premised in treating of fluid Inorganic formations of steam, thunder-clouds and falling rain, and of rarefaction of the air, by solar action.

Man is endued with intellectual and physical faculties adequate to employ at his pleasure, his own animal motive power, or that of any of the preceding means of propagating impulses, to move one portion of matter near another. He thus induces disturbances of electric matter, and the consequent further propagation of all such impulses in the variously modified forms of electric excitations. But there exist species of fishes, comparatively of a low order in the scale of created intelligences, which are capable of accomplishing extraordinary propagations of impulses through the medium of electric matter, in the modified form of electric shocks and sparks. What mankind can accomplish only indirectly, through artificially devised and constructed arrangements of electrical machines, the various electrical fishes are able to accomplish directly, through the natural mechanisms of the organs of their bodies. These fishes can, at their pleasure, propagate through the medium of electric matter a mechanical action, consequent on the combustion of food in their lungs, in the modified form of powerful shocks, capable of instantaneously killing smaller fishes constituting their prey, and of knocking down or stunning large animals, who may attack them.

The electrical action propagated by a species of eel—the Gymnotus, exhibited during a considerable time in London, produced the phenomena of brilliant sparks, sufficient to burn thin leaves of metal, and powerful shocks, sufficient to prostrate a man, who brought his hands into contact with the head and tail of the eel. Violent muscular contractions ensued on immersing the hand in the water near the eel whilst irritated, to induce him to make an electrical discharge.

This latter fact affords most conclusive reasons for believing, from analogy, that if one class of animals be found actually endued with the power of producing violent involuntary muscular contractions in all other classes of animals, that all such other classes of animals may be endued with the power of controlling a sufficient propagation of the same electro-dynamic action to produce voluntary contractions of the muscles of their respective bodies; and the consequent propagation of impulses in the modified form of animal motive power. Fire-flies, even whilst exerting the animal motive power necessary to sustain themselves on the wing, are simultaneously able to propagate the electro-dynamic action developed by the combustion of food in their lungs, in the modified form of electric flashes, capable of affecting the material nerves of the eyes of all sentient beings.

Although mankind are not created with natural organic mechanisms, capable of immediately propagating electro-dynamic action, like electric fishes and fire-flies, yet they have superior intelligence, and power of modifying the propagation of the same electro-dynamic action, developed by the combustion of food in their lungs, producing contractions of their muscles, and consequent animal motive power. They are thereby capable of exciting far more intense developments of electric excitation indirectly, by means of various sagaciously contrived machines, as we shall now proceed to show.

Considering then, that the universally diffused electric matter subserves the purpose of a medium specially designed for the propagation of impulses of mechanical force, which are developed by every mechanical movement of one body near another, it remains to trace out this simple principle in all its various applications, and to illustrate its truthfulness, by the tests of experimental demonstrations.

Various names have been applied to denote the different modes of producing electrical excitation. When one body is rubbed by another, as in the case of the common frictional electrical machine, this peculiar mode of excitation has been termed "Frictional," and "Mechanical;" and hence the term "frictional electricity," and "mechanical electricity," has originated. The excitation developed by means of heat, has been denoted "Thermo-electricity;" that developed by means of magnets, "Magneto-electricity;" that by means of the chemical decomposition of zinc by acids in the battery cell, "Galvanic" and "Chemical" electricity. The excitation developed by the organs of certain fishes, has been termed "Animal" electricity.

These several distinctive names appear to have been introduced into popular use for the convenience of arranging classes of facts of different modes of exciting electrical action, rather than for establishing any discrimination in the essential nature of the electricity excited. Indeed, Professor Faraday instituted a course of experiments for the express purpose of proving that there is no actual difference in the nature of electricity, however excited, and that all these kinds of "electricities" are identical.

Considering all electric excitation to be simply the propagation of mechanical action through the medium of electric matter, and that impulses of mechanical force are all identical in their nature, however excited, and however propagated, the preceding result, verified by Faraday, might be theoretically anticipated.

Without attempting to follow the popular classification of the modes of developing electric excitation, we shall continue to trace out the excitation and propagation of impulses of mechanical force through the medium of electric matter in the following order, viz.:

By the relative movements of masses of atoms at sensible distances from each other.

By the relative movements of atoms at insensible distances from each other.

By changes of temperature of groupings of atoms at insensible distances.

By the mechanisms of the organs of animals.

PROPAGATION OF IMPULSES THROUGH THE MEDIUM OF ELECTRIC MATTER, PRODUCED BY THE RELATIVE MOVEMENTS OF APPROXIMATED BODIES AT SENSIBLE DISTANCES.

The discovery of the fact of the propagation of mechanical action through the medium of electric matter was first detected by the friction of amber, as has been previously stated. The animal motive power applied in this case to rub the surface of one body over another has been shown to originate from the combustion in the lungs of the food produced by the electro-dynamic action of the sun. This source of electrical excitation, like that applied to turning the crank-handle of the electrical machine (previously referred to in describing the pith balls used as electroscopic tests, page 254,) originates from the mechanical action propagated through the medium of electric matter in exciting the mechanisms of the organs of plants.

As the movement of one portion of matter near another, serves to disturb the electro-static condition of both bodies, a continuous propagation of mechanical action from body to body, through the medium of electric matter, appears to be a consequence rationally to be anticipated.

The employment of amber, glass, resinous bodies, silk, &c., for the special purpose of exhibiting electric excitation, is resorted to for the reason that these particular substances, when reduced to a polarized state, do not become so speedily restored to their state of equilibrium, or electro-static condition, as the metals do, when they are similarly treated. For precisely the same reason tempered steel is selected in preference to iron and all other substances, to propagate more permanently electro-mechanical action in the modified form of magnetic excitation. A bar of iron subjected to friction, like a tube of glass or a stick of sealing-wax, is capable of developing similar excitation by becoming electro-polarized; but the more ready propagation of the electro-dynamic action among the molecules restores instantaneously their disturbed polarization to a counterbalanced static condition, as when a piece of soft iron is temporarily rendered magnetic by contact with an excited magnet, or by the proximity of an electric current.

The process of friction is resorted to by the inhabitants of some of the isles of the Pacific Ocean, for the purpose of producing electro-dynamic excitation for kindling fires; and people more advanced in the arts of civilization are accustomed to accomplish the same result by means of "friction matches," besmeared with certain groupings of elementary atoms reduced to constrained electro-polarized conditions.

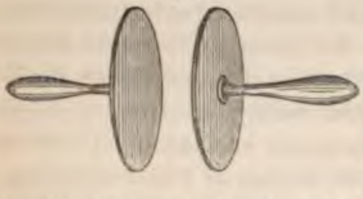
The friction of a body represents a succession of contacts of different portions of the surfaces of two bodies. The principal difference between the simple *contact* of two bodies, and the *friction* of them, consists in the preceding fact that the latter represents a succession of contacts, and the former a single one. In analyzing this process of excitation of electricity, the friction becomes reducible, therefore, to successive movements of portions of matter with their respective atmospheres of electric matter, toward and from each other.

The fact of the development of electrical excitations by bringing different kinds of substances into contact with each other, appears to have been first noticed by the celebrated Volta, about the year 1801.

This discovery constituted an important era in the science of electricity, and immediately led to the establishment of a new theory, denominated the "CONTACT THEORY."

To demonstrate the fact that electricity is excitable by the contact of different metals, Volta made use of two round plates, one of zinc, and one of copper, of about two inches in diameter, ground perfectly smooth, and adapted to fit each other's surfaces, having insulating glass handles affixed to their centres, as shown in the figure. Both plates may thus be brought into contact with each other whilst insulated from the touch of the hand.

Fig. 57.



By bringing the plates together, and touching one of them, and by then separating them, he established the truth of the fact, that when the metals copper and zinc are brought into contact, and then separated in an insulated natural electro-static condition, electric excitation becomes manifest, as tested by electroscopic instruments.

By repeatedly bringing these plates into contact, and separating them, each time touching with one of them the plate of the electroscope invented by him, see fig. 19, Volta succeeded in propagating to the gold leaves mechanical action through the medium of electric matter. This experiment admits, also, of verification, by means of Hare's electroscope, figure 18, page 203, as has been premised.

That this very extraordinary phenomenon of the propagation of electro-dynamic impulses is not due to any original innate cause of natural motive power inherent in the atoms of these two metals, as supposed by Volta, admits of demonstration. This appears by recurrence to the facts that have been narrated of the great quantity of organic carbon, or coal reduced by solar action to the state of the fuel consumed in the smelting furnace, to reduce the atoms of zinc from their natural permanent static condition of ores to the temporarily excited and constrained static condition of a pure glittering metal. And also of the extent of combustion of organic carbon reduced by solar action to the state of the food burnt in the lungs to develope the animal motive power propagated to the zinc and copper plates to bring them into contact with each other. The electric excitation in this case is due to the propagation of the electro-dynamic action of the sun in the form of the organic action of animal motive power applied to move the plates of zinc and copper toward each other; whereby the electro-static condition of both are disturbed, accompanied by the ever-attendant result of electro-dynamic action.

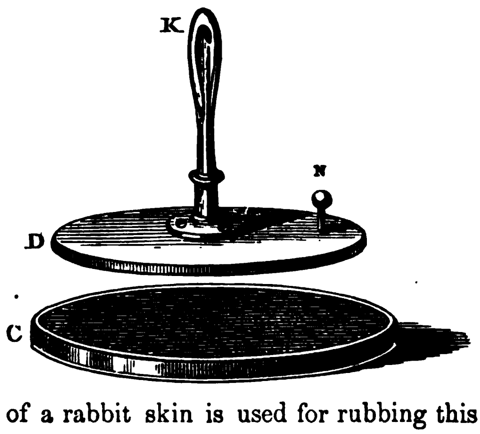
It is sufficiently manifest, that there could not have been any development of electrical excitation at all, nor any propagation of electro-dynamic action from either of the two plates of zinc or copper, *had they not been put in motion near each other* by the motive power originating from solar action.

To demonstrate that an *artificially excited* body will develope electrical excitation in another unexcited body with which it may be brought into contact, Volta invented a very simple kind of electrical machine, which he denominated

The Electrophorus.—The name of this electrical apparatus is derived from the Greek words signifying "*Producer of Electricity.*"

The *electrophorus* consists simply of a cake of sealing-wax, which material is selected as being a readily-excitable substance. A more tough and useful compound is commonly used, made by melting together equal parts of pitch and resin, combined with a little linseed oil. This composition, whilst in a melted state, is poured into a flat circular tin dish, having a rim of about half an inch in height, as shown at C. A round metallic plate, D, adapted to the size of this cake of resinous matter, is affixed to the insulating glass handle, K, by which the plate of metal may be alternately lifted from the cake of resin, and again brought into contact therewith.

Fig. 54.



When the dry fur of a rabbit skin is used for rubbing this cake of resin, or rather for striking it by repeated violent contacts with the fur side of the skin, a powerful excitation is artificially produced both in the cake and in the fur.

It is to be borne in mind, that the originating cause of the excitation of the cake of resin in this case is ascribable to the organic action employed to strike it with the fur. The animal motive power is derived from the combustion in the lungs, of the organic carbon reduced to the temporary static condition of food by the cause of solar action.

By means of this simple instrument the command is obtained of a body that remains for a considerable time in an excited or polarized state, and which admits of being readily employed at pleasure to induce excitation—that is, electro-polarization, in any other bodies which may be selected to be brought near to it.

Whenever it is desirable artificially to propagate electro-dynamic action from the cake of resin to some adjacent body, the circular plate of metal is taken by the tip of the glass handle, and brought into contact with the cake of resin, and at the same time the finger is brought to touch the plate. Then the finger is to be withdrawn, and the plate removed by holding the tip of the glass handle.

The electro-dynamic action induced in the plate by contact with the wax may be propagated to any portion of adjacent matter, which the operator may select and bring near it.

By leaving the plate of metal in contact with the surface of the cake of resin, this action and reaction produce the result of a complete *electro-static condition*, which, in a dry, warm place, remains continuously during days and even months. But if the action of any organic forces of animal motive power, or inorganic forces of natural motive power originating from the cause of solar excitation, as has been previously detailed, be brought to bear upon these plates, so as to separate them, then their temporary electro-polarized condition becomes disturbed, and the impulses, which are counterbalanced by action and reaction to produce this electro static condition, *become developed as two equal and oppositely-directed mechanical forces.*

By the mechanical laws of the resolution of forces, we are thus theoretically led to anticipate that which never fails to be verified by the fact of every experimental disturbance of the electro-static conditions of terrestrial matter; that the oppositely-directed and counterbalanced electro-dynamic impulses are absolutely and completely resolved, exhibiting their oppositely-directed actions on the two opposite surfaces of the bodies brought into contact or rubbed together.

This peculiar result is ascribable to the perfect mobility of electric matter, which can never be caused to exhibit dynamic action without a simultaneous reaction in an opposite direction. It is one of the most important fundamental facts of the science of electricity, connecting it by this inseparable action and reaction with the science of mechanics. In this connection it will hereafter come under a more scrutinizing examination, as constituting the basis of the two popularly adopted theories of electricity, denominated the "Two Fluid" and "Single Fluid Theory."

The electrophorus is used practically for producing instantaneous light, by causing an electric spark, always excitable in an instant from the plate on being lifted from the cake of resin, to kindle a jet of hydrogen gas artificially arranged to issue from a small apparatus, containing a lump of zinc in acidulated water.

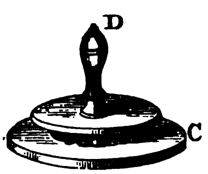
The plate, by dexterous manipulations, admits of being brought into contact with the cake of resin, and lifted therefrom nearly a hundred times per minute; and consequently it may be excited and discharged as often. But to facilitate this operation, instead of using the finger each time to touch the plate, strips of tinfoil are arranged upon the cake, so as to serve as a substitute for the tedious manipulation with the finger.

The intensity of the electric disturbance excited by the approximation of two different kinds of metals, or of other bodies, must be greater or less in proportion to the difference of intensities of their electro-static or electro-polarized conditions. Although the opposite electrical actions and reactions may be exactly counterbalanced among the atoms of the mass of a simple or compound substance, when considered absolutely by itself, yet this fact is no proof that the relative electro-static conditions of any two such bodies are so precisely similar as not to disturb each other's electro-static conditions when brought into contact together.

The mechanical *pressure* of bodies, as well as friction and contact, propagates electro-dynamic action. Elastic India-rubber, or caoutchouc, developes extraordinary electric excitation by sudden compression.

Sparks issue in vivid coruscations to a distance of several inches from between the rollers used for compressing sheets of this material in the process of incorporating it into manufactures of cloth. In certain processes of calico printing, the India-rubber, dissolved in spirits of turpentine and alcohol, and mixed with ultra marine blue, or other colored substances, is passed with great pressure between the engraved copper rollers and the cloth to be imprinted therewith. A torrent of sparks I have noticed to issue from the compressed India-rubber, too intense to be sustained by the knuckles, held near them, without absolute pain. Indeed, the process of printing with this material was finally suspended from the danger of burning up the building and machinery employed, the sparks having actually set fire to the composition of turpentine, alcohol and India-rubber, and caused the cloth in the machine to be burnt up.

Fig. 55.



The pressure of India-rubber between two plates of melal, the upper one being attached to a glass handle, D, as shown in the figure, will develope electric excitation.

The mechanical compression of air beneath the piston of a forcing syringe is one of the most remarkable modes of propagating powerful mechanical action through the medium of electric matter, by producing constrained electro-polarizations of the molecules. On a small scale, the process of compressing air beneath the piston of a tight cylinder, having a little tinder placed therein, has been commonly employed as a ready mode of kindling the tinder for igniting other bodies. The animal motive power is thereby propagated through the medium of electric matter in the modified form of the excitation of heat, as has been stated of the propagation of the same action through a fine wire.

The preceding operations have been practically effected on a great scale, with a powerful steam engine, in the city of New Orleans, for the express purpose of producing ice economically on the spot, even in midsummer, as an article of luxury of commercial value in a warm climate. Whatever may be the final result of the experiment, it serves beautifully to illustrate the system of the propagation of mechanical action, originating from the combustion of fuel in the furnace of a steam engine, to electro-polarize, by compression, the particles of air beneath a forcing piston. The mechanical action is next propagated from the polarized particles of air, in the modified form of heat, to a portion of water arranged in contact therewith, which becomes reduced to the state of steam. In this constrained opposite electro-polarized condition each molecule repels the other, until re-acted upon by the cold sides of the condensing vessels, and by a jet of cold water. When relieved of the extreme mechanical pressure by being drawn off into a separate vessel, the particles of air react by a reversed polarization upon the molecules of water placed therein; whereby the latter becomes in turn polarized,—the reverse, however, of the former case; for instead of being reciprocally repellant, as in the state of steam, they become reciprocally urged toward each other, and solidly grouped in crystals of ice. A very considerable quantity of ice is thus speedily obtainable, and at a cost less than might be theoretically supposed.

By this very interesting process of changing the polarizations of the molecules of water, both ice and steam are simultaneously producible by the combustion of fuel in the furnace of a steam engine.

The percussion of a hammer, continuously and violently repeated upon the refractory metal of iron on an anvil, is sometimes resorted to by the smith for the purpose of kindling electro-dynamic excitation on the hearth of his forge. The percussion of flint and steel has been practised from the earliest ages to produce similar excitation.

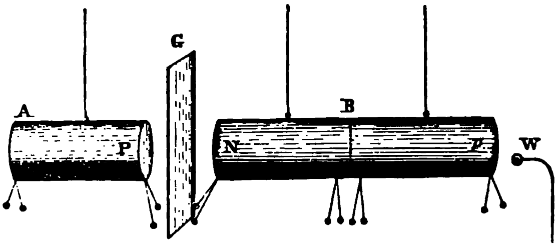
The whole science of electrical excitation is based on the fact of the action and reaction of electric matter existing in electro-static conditions in connection with groupings of elementary atoms. Impulses are propagated from atom to atom, and body to body, and even through sheets of glass and intervening spaces of air. Every movement of one portion of matter even *near* another, disturbs the electro-static condition of such bodies, and induces a consequent electro-dynamic action.

This latter mode of inducing the reciprocal disturbance of electric matter has been denominated INDUCTIVE ACTION.

The approximation and recession of atoms, or masses of matter, with the electrical atmospheres naturally enveloping them, are found experimentally to be a requisite for producing the disturbances of the state of rest of electricity, constituting the phenomenon of electric excitation. It may hence be adopted as a law of electro-dynamic science, that *no continuous electric action can be excited in any kind of electrical apparatus, without the continuous movement of their parts, or of some intermediate element of matter.*

The discovery of this principle of electric excitation appears to have been originally made by Otto Guerick, as may be noticed by reference to his description of the excitation of a body, merely by approaching near to it, some other body, that has been previously excited, without actually touching it, and with a space of air, or a sheet of glass intervening between them. This fact is exhibited in the annexed figure, where A represents an excited body insulated by a silk string, and approximated to an unexcited body, B, insulated by silken cords, and with a sheet of glass, C, interposed between them.

Fig. 56.



By moving A gradually toward B, it is discovered that the pairs of pith palls suspended from B, become more and more divergent; and on withdrawing A from B, the same electroscopic balls become less and less divergent, until they cease finally to render manifest by their continuous divergency, the least evidence of any disturbance of their natural electro-static condition. At the same time the pith balls suspended from A become still more divergent, on being approximated to B, and are restored to their former divergency on being withdrawn.

This was a very important discovery of an extraordinary propagation of electro-dynamic action, not only through intervening spaces of air, but even through an intervening dense sheet of glass, which is considered as a *non-conducting* substance. The experiment serves beautifully to illustrate the action and reaction of the electric atmospheres reciprocally between two bodies not in contact.

By again approximating the excited conductor A more closely to B, the action of the electric atmosphere of the former finally acts so powerfully in disturbing the previous electro-static condition of the latter, as to induce a further extended disturbance of the natural polarized condition of the adjacent knob of the wire W, connected with the mass of the earth. The shock of this action and reaction is propagated through the vibrating electric matter pervading the surrounding atmosphere, still further inducing a propagation of impulses of mechanical force to disturb the natural electro-static condition of the nerves of the eye, recognizable by the tribunal of human intelligence as the perception of light. At the same instant the shock of this mechanical action and reaction induces a vibration of the air, and the sensation of SOUND. And were the two conductors, A, B, considered as representing the dimensions of two large clouds approximated by the winds in the heavens, the intensity of the electro-dynamic action propagated between B and the surface of the earth through the medium of the atmospheric air, would exhibit the phenomenon of lightning. This action, if from a very extended excited mass propagated through a fine wire, would produce such an excessive vibration thereof, as to affect the nerves of the hand grasping the wire, with the sensation recognizable as that of *heat.*

At the instant after the reaction of the electric matter existing in connection with the mass of the earth, the disturbed electric matter of the conductor B, and of the adjacent knob, W, connected with the earth, become reduced to a counterbalanced electro-static condition, as tested by the drooping of the pith ball electroscopes appended thereto.

Let the conductor A be now withdrawn from B, and it will be found that the electric atmosphere of B becomes again disturbed by being relieved of the constraining influence of the excited electric matter A; and the pith balls suspended from B will again become divergent. A second reaction of the disturbed electric matter ensues between the knob W and B, reproducing precisely the same phenomena of an electric spark and shock.

In explaining this experiment, a portion of the electric matter naturally existing in an electro-static condition in connection with B is supposed by electricians to be transferred in a "disruptive discharge" to the earth; and in the latter case this deficiency is supposed to be similarly restored from the earth.

The pith balls suspended from the middle of B, are found by experiment to continue drooping, whilst those at the ends N P continue divergent, thus demonstrating that the electro-dynamic action is confined to the two extremities of the excited conductor. This peculiar action developed at the ends or poles of excited bodies, denoted by the term polarization, exhibits a general law of electro-dynamic action at the extreme ends of all excited bodies.

To prove this fact, it is only necessary to sever the conductor B at the middle part, by dexterously swinging the ends asunder whilst sustained by the silken cords. It will be perceived that the pith balls suspended from the section that constituted the middle part then become divergent. The same result of the cessation of the development of dynamic action occurs at the two N and S poles of a bar magnet when conjoined in contact with each other. The middle part or conjoined ends, cease to attract iron filings, until they are again separated, when the dynamic action is restored to the ends. Thus the principle of the *polarization* of bodies by the action of "electricity" and of "magnetism" are precisely similar. This fact also corresponds with that of the electro-polarization of the pith balls pressed against an excited body, as has been previously noticed. A similarity also of the propagation of electric and magnetic impulses through a sheet of glass and other non-conducting substances takes place; and as the N pole of a magnet induces the opposite S polarity in a bar of iron brought near it, so the dynamic action of the end of the conductor P, *positively* excited, induces an opposite negative excitation, denoted by N; whilst the further end exhibits, like the two opposite ends of magnets, opposite dynamic impulses, thus demonstrating the similarity of the electro-dynamic impulses developed by an insulated electrically excited body, and a magnet.

It is usual to affirm, as above stated, that opposite poles of magnets, and oppositely excited bodies, attract each other. This use of the term "opposite" may convey the idea, that about the respective N and S poles of magnets, placed end to end, the currents circulate in opposite directions to each other. The reverse of this is the fact, as has been explained in reference to the figures A B of the Floating Rings, page 223. About the N pole of one magnet, and the S pole of another, arranged end to end, the electro-dynamic action is propagated in similar directions, thus sustaining the general law of Attraction between similarly moving currents. The same law is presumed to hold good when applied to the polarization of electrically excited bodies, as illustrated by the preceding figure.

In the early experiments of electricians, the process of friction was accomplished by rubbing very large sticks of sealing-wax, and large glass tubes, with dry warm cloths, or the fur of animals applied with the hand. It was not until the year 1705 that the improvement was first introduced, by Hawksby, of employing a glass globe, fixed on an axis provided with a crank, to be turned by the hand for exciting electricity.

In the first stage of this improvement, the rubber was held by manual pressure against one side of the revolving globe, whilst an attendant mounted on a cake of resin, or on a stand supported by glass legs, held a row of pointed wires against the opposite side of the globe.

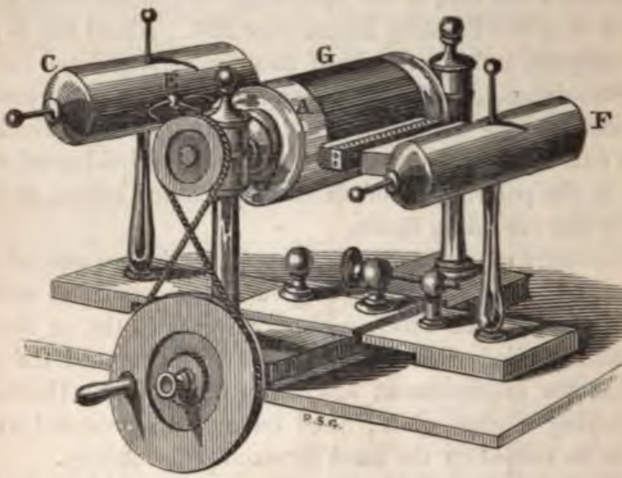
Boze and Winkler made still further improvements by fixing permanently to the frame used to support the revolving globe, two posts of baked wood (and subsequently of glass), the one to sustain the rubber, and the other to sustain the row of pointed wires, thus dispensing with the labor of two attendants.

With these gradually introduced improvements, the apparatus for exciting electricity has been reduced to the form a machine, denominated the "Frictional Electrical Machine."

Although these machines are now too familiarly known to require an elaborate description, yet a brief review of the specific arrangements of their working parts may advantageously be considered, as illustrating the philosophical principles of electrical excitation.

Frictional electrical machines were first constructed to be operated by the *successive approximations* or *contacts* of the parts of the revolving glass cylinder, A, against the parts of a rubber attached to a hollow metallic cylinder, F, mounted on a pillar of glass. This pillar is sustained on a sliding base-board at the bottom, capable of being moved by a screw towards the glass cylinder, to regulate the intensity of the pressure, and consequently of the friction of the rubber.

Fig. 57.



The rubber is made of leather stuffed with horse hair, to constitute an elastic cushion.

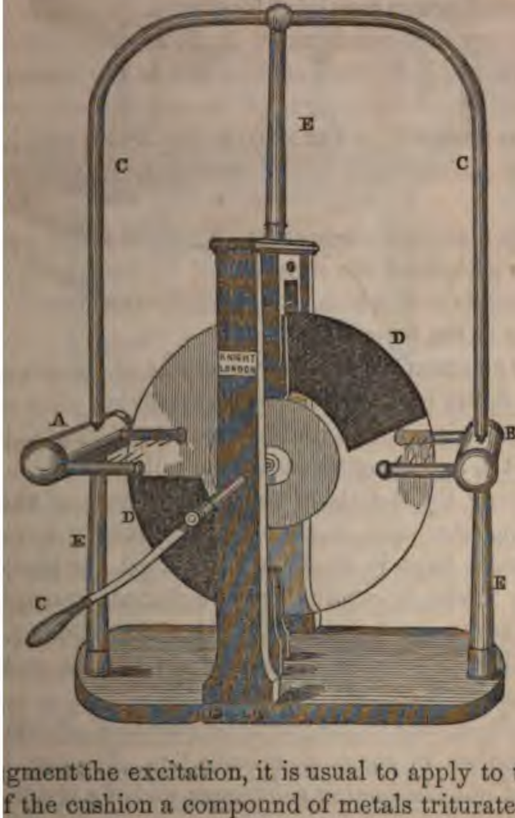
Another hollow metallic cylinder, termed "a Prime Conductor," is represented at E, furnished with a row of pointed wires facing the glass cylinder, designed to serve for collecting the electricity excited therefrom. To prevent the escape or propagation of the electro-dynamic action from the prime conductor, it is *insulated* by the intervention of a non-conducting glass pillar. A flap of silk, G, is attached to the cushion, and is spread out over the top of the revolving cylinder, to suppress the dissipation of the electrical action by the reaction of the air, before it reaches the row of points at E.

A revolving movement may be imparted to the glass cylinder by the animal motive-power of the human hand applied to

rank-handle attached to the pulley W. Into this pul-
ved score is turned, adapted to receive the cord that
om it to a similar groove in a pulley attached to the axis
ss cylinder.

onductor E has also been denominated the *positive* con-
contradistinction to the conductor attached to the rub-
h is denominated the *negative* conductor, the former be-
sed to contain an accumulation, or "positive" excess of
and the latter supposed to have yielded up a portion
ural share of electricity, and to be reduced to a "nega-
e.

Fig. 58.



gment the excitation, it is usual to apply to the rubbing
f the cushion a compound of metals triturated with lard.
, by weight, of tin, and two parts of zinc, are melted
, and mixed with six parts of mercury, which are to be

well stirred together until solidified. The brittle compound is then pulverized in a mortar, and mixed with a sufficient quantity of lard to reduce it to the consistency of a paste.

A superior improved *Plate Electrical Machine* has been introduced, which has superseded the use of the cylindrical machines, one of which is represented in the preceding figure.

The glass plate is caused to revolve by means of the crank handle C, attached to an axis passing through the plate, which is supported between two pillars. Attached to the inner sides of these pillars are four cushions, compressing the plate between them at the upper and lower portions of the disc, each having flaps of silk, D D, appended thereto. The intensity of the pressure of the cushions is regulated by screws.

The two opposite conductors, A B, are supported by two stout glass pillars, E E, fixed at each end of the mahogany base board, on which the other parts of the machine are mounted.

The brass arch, C C, is sustained at the centre and lower ends by the glass pillars E, E, E, and connects the two conductors A B.

The large electrical machine at the Polytechnic Institute, in London, has a plate of the diameter of 7⅓ feet, the sparks from the huge conductor of which, it is stated, "are nearly sufficient to fell a man to the floor."

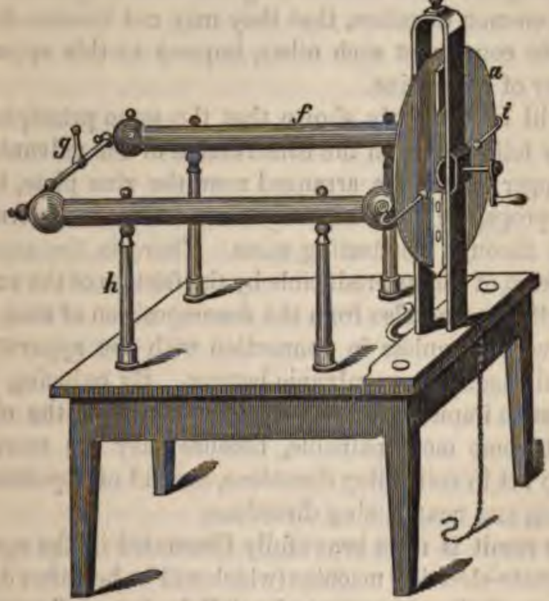
Another common mode of arrangement of the working parts is shown in figure 59, where the glass revolving plate is denoted at *a*, the connecting wire with its rows of points at *i*, the prime conductor at *f*, and the glass insulating pillars at *h*.

By scanning the details of the arrangement of the parts of the preceding machines, it is to be particularly noticed here, that the system kept in view throughout all the plans of their construction is simply confined to two distinct principles.

1st. To move one portion of matter near another in order to disturb the natural state of rest of the electric matter existing in connection with both bodies.

2d. To direct the consequent propagation of the electro-dynamic impulses in some one specific line of action, by means of interposed non-conducting substances, and of a continuous line of conducting substances, to concentrate them on a determinate point. Otherwise, the electro-dynamic impulses would become diffused in every opposite direction, and be unavailable. By counteracting each other, they would become neutralized and imperceptible.

Fig. 59.



To carry out the first principle, a selection is made of glass, sealing-wax, fur, silk, or of some other similar *non-conducting* body; and their natural electro-static condition is disturbed by mechanical motion of their approximated parts. A bar of iron may be used similarly to a stick of sealing-wax, or glass tube, for developing electrical excitation; but from the instantaneous diffusion of the electro-dynamic action throughout all parts of the metal, its polarization ceases immediately. The greatest precautions of artificial insulation by glass, sealing-wax, &c., are requisite for the development of the electric impulses in metals in any one specific direction, with sufficient intensity to become appreciable. The friction of metals, when intense, propagates electro-dynamic action in the modified form of heat, as occurs when a fine wire is used to propagate electric action.

The pointed wires are introduced to determine the electro-dynamic action in the specific direction of the insulated prime conductor of the electrical machine, to be subsequently distributed by the pathways of conducting wires in other directions, required for concentrating the action upon some one object. This arrangement for determining the electro-dynamic impulses to one common direction, that they may not become diffused, or turned to counteract each other, imparts to this apparatus the character of a machine.

It will be presently shown that the same principles are necessarily followed up in the construction of the galvanic battery. The copper plates are arranged near the zinc plate, to receive and to propagate the electro-dynamic action in determinate directions through connecting wires. There is the same extent of this kind of action producible by the friction of the surface of a glass cylinder, and also from the decomposition of zinc, although undiscoverable, unless in connection with the apparatus of an electrical machine, or galvanic battery. By reducing the electro-dynamic impulses to one common direction, the observable effects become more palpable, because they are more concentrated to act in coinciding directions, instead of opposite counterbalancing and neutralizing directions.

This result is most beautifully illustrated in the operation of the Magneto-electrical machine (which will be hereafter described), by means of the apparatus of a "Pole-changer," employed to convert the alternate and oppositely directed ebbing and flowing surges of the electric matter in the spiral coils of wire, in *one uniform direction*, to represent the continuous electro-dynamic action of a common frictional electrical machine, or galvanic battery.

The successive contacts of one portion of matter with other portions of matter, constituting the mechanical action of friction, is adequate to developing electro-dynamic action under apparently the most unfavorable circumstances. Even with the temperature of the atmosphere at Zero, (Fahr.) I have noticed that the friction of the wooden runners of heavily laden sleds on the surfaces of snowy roads produces this kind of excitation, sufficient to melt the snow beneath them, and even to produce steamy exhalations. So familiarly known is this fact to the drivers of these vehicles, that it is their common practice to leave them, when stopped for a time, upon pieces of wood, to prevent the excited runners from melting the ice beneath them, and from afterwards becoming frozen fast to the spot. Without this precaution it requires the aid of levers, and the percussion of heavy blows, to detach them.

The excitation of the electrical machine, and galvanic battery, may be employed to produce the same phenomenon of heat and melting of ice, when propagated through fine conducting wires, as has been before stated; thus demonstrating, that the same electrical cause is adequate to producing both of these effects.

The mechanical contacts of the particles of liquids, as well as of solids, render manifest palpable impulses of electrical action. By discharging a fine shower of mercury against the surface of glass under the exhausted receiver of an air pump, or by forcing a current of air from bellows against a window pane, similar manifestations of disturbances of their electro-static conditions are exhibited. Every gust of wind must consequently produce electrical currents on the surface of the earth.

The violent movements of the rushing waters of the cataract of Niagara produce so great an electro-dynamic excitation, as to send forth a volume of steamy vapor, which ascends like a perpetually rising curtain of mist in front of the grand cataract. The ascending cloud of vapor becomes visible to the traveller at the distance of several miles from the falls.

These vapors veil the termination of the descent of the falling waters, serving to increase the sublimity of the scene by partially shrouding it in mysterious obscurity. Every pointed twig and spire of grass on the verge of the precipices in the immediate vicinity of the rising vapors, glitters with the drops of the water attracted by them as conductors or propagators of the excited electro-dynamic action. Thus on this spot, where there is developed a greater extent of mechanical action than on any other spot on the surface of the earth, there is also developed an extraordinary extent of propagation of the same action through the medium of electric matter, as has been recapitulated of the production of similar steamy vapors by the silent electro-dynamic action of the sun on the quiet surface of the ocean.

In experimenting on the fine spray arising from the violent movements of the waters of cascades, Volta and Tralles ascertained by repeated experiments with electroscopes held in the misty atmosphere, that the phenomenon of electric excitation becomes developed. There are, therefore, ample reasons for the belief that the beautiful "dew theory" of Dr. Wells may be resolved into the propagation of electro-dynamic action.

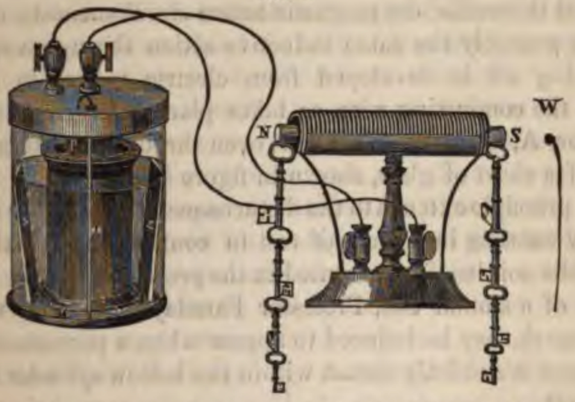
This idea appears to be confirmed by facts which have been noticed in Wilkes' Narrative of the United States' Exploring Expedition, on the voyage from Madeira to Rio Janeiro, (vol. I, page 37,) where it is stated that scarcely was the sun set, before the ship was covered with heavy deposits of dew, so as to become quite wet with it. Captain Wilkes remarks, that "one of the essential requisites supposed necessary by Dr. Wells for a deposit of dew, was certainly wanting in this case, viz., that *the temperature of the body on which it was deposited should be considerably lower than the surrounding air;* the temperature of the air and ship having remained the same for several days, at about 78°; all objects, hammock-cloths, spars, sails, and rigging, so far as could be ascertained, showed the same." And, again, on the summit of Mauna Loa, Hawaii, he observes, that when the dew-point could be obtained by Pouillet's hygrometer, electricity was found to be easily excited.

The violence of the mechanical friction of the falling waters of cataracts induces the propagation of electro-mechanical action in the re-formation of the same vapor of water, as was originally induced by the solar action that elevated the floods. By the change of these molecules of vapor to their natural static condition of water in the form of dew-drops, electro-dynamic action becomes again propagated, as tested by Volta and Tralles.

In all the preceding examples of electric excitation, the propagation of the electro-dynamic action is effected by moving one body near another. As the propagation of the impulses of mechanical action is extended through the medium of the electric atmosphere environing and accompanying such relatively moving bodies, there is no necessity for the actual movement of the passive matter of such bodies, provided the electric matter itself be moved therein to propagate the impulses. If two bodies be fixed side by side, like the two conducting wires shown at page 220, figure 20, and electro-dynamic action be propagated through them from an excited galvanic battery, these bodies at rest may be moved thereby, as has been illustrated.

That the same electric excitation may be induced by the disturbance of electric matter existing in connection with bodies at rest, as is producible by the relative movements of such bodies near each other, admits of demonstration by the following experiment:

Fig. 60.



Within the hollow cylinder, composed of the multiplied coils of a conducting wire, forming a helix, as shown in the figure, insert a piece of iron, N, S, resting on a piece of non-conducting glass placed therein to sustain the piece of iron from contact with the surrounding wire coil; and let there be arranged the knob of another conducting wire connected with the ground, near the end, S, corresponding with the similar knob, W, of the preceding figure 56.

At the instant the battery current is propagated through the wire coil, the electric matter existing in a state of rest in connection with the piece of iron, N, S, becomes disturbed by the presence of this approximated current, and an electric spark becomes apparent between the end of the iron, S, and the knob. Impulses of electro-mechanical force are developed between the ends of the iron, N, S, and other pieces of iron, such as keys, screws, &c.; which are held up thereby so long as the circumambient current continues to be propagated through the coil of wire. When the current is suddenly cut off, by detaching one end of the wire from its connection with the galvanic battery, a spark is again seen to occur between S and the adjacent knob; then the suspended keys suddenly drop therefrom, in the same manner as the divergent pith balls, suspended from the conductor, B, fig. 56, drooped on the occurrence of the reacting spark from the adjacent knob, W. This experiment demonstrates that on counteracting the constrained electro-dynamic condition of the bar of iron by the reaction of the electric matter of the mass of the earth through the adjacent knob of the conducting wire connected therewith, the magnetic action simultaneously ceases.

Thus precisely the same inductive action through a space of intervening air is developed from electric matter in motion through the conducting wire, as takes place between an excited conductor, A, and adjacent bodies, even through an intermediate screen of a sheet of glass, shown in figure 56.

This principle extends to the disturbance of the electric matter, naturally existing in a state of rest in connection with the iron wire of the coil itself, represented in the preceding figure. From one end of a similar coil, Professor Faraday discovered that an electric spark may be induced to appear when a permanent steel bar magnet is suddenly thrust within the hollow cylinder formed by the coil.

The movement of every kind of matter rapidly toward and from permanent steel magnets serves to disturb the natural static condition of the electric matter existing in connection therewith, and to induce resultant electro-dynamic action.

IMPULSES PROPAGATED THROUGH THE MEDIUM OF ELECTRIC MATTER BY THE MECHANICAL MOVEMENTS OF MAGNETS NEAR CONDUCTING BODIES, CONSTITUTING MAGNETO-ELECTRIC EXCITATION.

Immediately after the discovery of the excitation of magnets by means of electricity in motion, it became a frequent subject of experiment to produce the excitation of electricity by means of magnets in motion. A course of experiments was instituted by Professors Faraday and Forbes, expressly to verify this anticipated result. They accomplished this interesting discovery, and laid the foundation for a new mode of producing electric excitation, which has received the appropriate name of "MAGNETO-ELECTRICITY."

The earliest account published of the first successful experiment in exciting electricity by the influence of magnets, appeared in April, 1832, in the "Annals of Philosophy," as communicated by Professor Faraday.

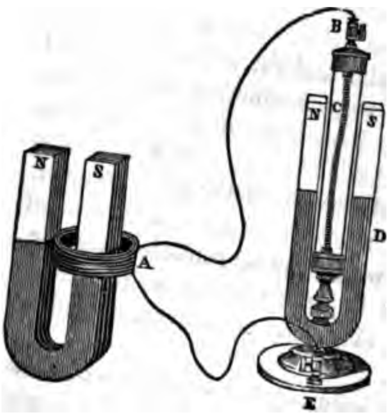
"If a wire, connected at both extremites with a galvanometer, be coiled in the form of a helix around a magnet, no current of electricity takes place in it. This is an experiment which has been made by various persons hundreds of times, in the hope of evolving electricity from magnetism; and, as in other cases in which the wishes of the experimenter and the facts are opposed to each other, has given rise to very conflicting conclusions. But if the magnet be withdrawn, or introduced into such a helix, a current of electricity is produced *whilst the magnet is in motion*, and is rendered evident by the deflection of the galvanometer. If a single wire be passed along a magnetic pole, a current of electricity is induced through it, which can be rendered sensible. Whenever, also, a piece of metal is moved near a magnet, so as to intersect the magnetic curves, electricity is evolved, according to very simple laws."

The earliest contrivance for inducing the excitation of electricity by the approach and withdrawal of magnets, was originally accomplished by Faraday in the year 1831. He used a bar of soft iron, instead of a permanent magnet. By inserting this piece of soft iron into the helix coil, as shown in the preceding figure, and by then touching the projecting end of the bar of soft iron, whilst thus environed by the coils of wire, with the pole of a steel bar magnet, the bar of iron becomes instantaneously a magnet. It ceases, also, instantaneously to be a magnet, when the permanent steel magnet is withdrawn from contact therewith. As this operation of exciting temporary magnetism in a bar of iron already inserted within the helix coil of wire, admits of being more rapidly accomplished, to exert a sudden action in exciting the electricity naturally existing in connection with the metal of the wire coil, than can possibly be effected by means of thrusting a permanent magnet into the same coil, the phenomenon of the electric excitation becomes reduced to more sudden and violent ebbing and returning surges. This is rendered manifest by more brilliant sparks, and more powerful shocks o the human body.

But instead of the ends of the wire coil being connected with a galvanic apparatus, as in the preceding figure, they are to be connected with a galvanometer, page 231, figure 28, which is to be used as a test of the electric excitation.

A simple contrivance for exhibiting the excitation of electricity by moving a body near a magnet, is shown in figure 61. The ring, A, formed of a wire, wound into spiral coils, and having its ends connected with a gold-leaf galvanoscope, figure 30, page 233, is to be slipped over the pole, S, of a horseshoe magnet. The gold-leaf will be sensibly moved toward the spectator during the continuance of the descent of the ring over the pole; and an opposite movement will occur during the continuance of its ascent.

Fig. 61.

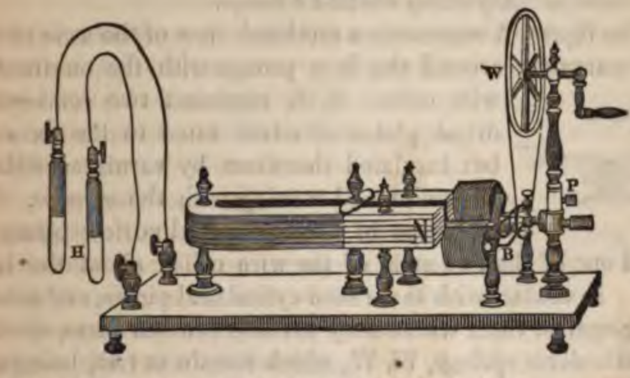


These reciprocating movements back and forth produce corresponding reciprocating movements back and forth of electric surges, and of mechanical impulses deflecting the strip of gold leaf in exactly opposite directions.

A powerful magneto-electrical machine is shown in the following figure. The driving wheel, W, may be turned either by the hand, or by a band moved by steam power or water power.

From the wheel, W, a band is extended around a smaller wheel or pulley to be turned thereby. The upper part of the pillar, P, slides into the lower part, and admits of being fixed higher or lower by the binding screw, P, so as to tighten the band as desired. An U magnet, N, is fixed horizontally with its two poles as near to the ends of the armature, B, as will allow the latter to revolve without touching them. The armature is nade of a piece of soft iron, bended twice at right angles to esemble also the shape of the letter U. Around each of its legs wound a helix of fine wire coated with thread. This piece of iron, with its environing coils of insulated wire, is fixed upon an axis extended from the pillar P to another pillar erected between the poles of the magnet. This axis is caused to revolve rapidly by the band from the multiplying wheel, W.

Fig. 62.



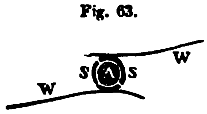
Both of the arms of the revolving bar of iron are rendered magnetic, for an instant, as they successively pass the two approximated poles of the permanent steel magnet, N; and they cease for an instant to be magnetic on passing away from the influence of these two magnetic poles. The leg of the iron bar which approaches the N pole acquires the opposite south polarity, and the other, the opposite north polarity. The intensity of the excitation increases until the ends of the armature are exactly opposite to the ends of the poles of the steel magnet, and then diminishes to a minimum, when they stand crosswise to each other. By the continuance of the motion, each leg of the iron armature becomes oppositely excited on approaching the opposite pole.

These rapid transitions of magnetic excitations in the revolving bar of iron induces equally rapid transitions of excitation of the electric matter existing in connection with the coils of wire, wound around them both continuously. But it is manifest on inspecting the arrangement of these two coils of wire revolving about the axis, that their ends cannot remain connected with any stationary portion of the apparatus, as they would become broken off by the revolving movement. Consequently it becomes necessary to have recourse to additional arrangements of connections of the ends of the coils of wires with other conducting wires, extended to the bodies to receive the shocks propagated therefrom.

To overcome this difficulty, Dr. Page has invented the simple, but very ingeniously contrived mechanism, which has been denominated a " *Self-acting Current Changer.*

In the figure, A represents a sectional view of the axis of the spindle carrying around the iron prongs with the environing wire coils. S, S, represent two semi-cylindrical plates of silver fitted to the axis A, but insulated therefrom by varnished silk or otherwise, and turning with the spindle. To each one of these semi-cylindrical pieces is soldered one of the two ends of the wire coiled about the iron prongs. In contact with these semi-cylindrical pieces, and gently pressing against them whilst they revolve beneath them, are the two elastic silver springs, W, W, which remain at rest, being soldered permanently to the ends of the conducting wires that are designed for propagating the electric action to the bodies to be affected thereby. By this arrangement a continuous metallic contact is preserved between the ends of the wire coils revolving on the spindle, and the ends of the conducting wires leading to the two screw cups, shown at the opposite end of the base-board of the machine.

Fig. 63.



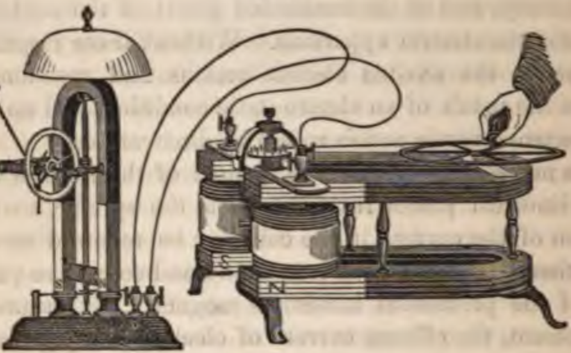
By means of the mechanism of the revolving armature and coils, several thousand changes in the directions of propagation of the ebbing and refluent electric surges may be produced in a minute, when the wheel W is very rapidly turned by the crank-handle, or preferably by steam or water-power. The intensity of the ebbing and returning surges of electric action is correspondingly augmented with the rapidity of their movements toward and from the poles of the permanent magnet.

Although the directions of these ebbing and returning surges are reversed twice during each revolution, yet the connections of the two semi-cylindrical pieces are such as to turn all the ebbing surges in one direction, by one of the connecting pieces, S, and all the refluent surges uniformly in an opposite direction through the opposite connecting piece. This peculiar adaptation of the Current Changer to produce uniform currents by modifying the opposite directions of the ultimately ebbing and flowing electric actions and reactions, which would otherwise counterbalance and neutralize each other, serves beautifully to illustrate the general principle of the construction of all kinds of electrical machines; viz., that of determining the propagation of the electro-dynamic action to one common direction, instead of allowing the rapidly vibrating actions and reactions to neutralize each other. The operation of the mechanism of the current changer represents that of the row of pointed wires on the prime conductor of the electrical machine;—of the copper or platinum plates in the galvanic battery, and of the contracted joints of the soldered bars of the thermo-electric apparatus. Without these respective arrangements, the excited electric actions and reactions would produce the result of an electro-static condition, and no determinate electro-dynamic action would be discoverable.

It is necessary to adjust the contact of the springs with the semi-cylindrical pieces revolving with the spindle, so that the direction of the current in the coil may be reversed at the moment when the ends of the iron prong and coils have passed the poles of the permanent horseshoe magnet. By means of this arrangement, the effluent current of electric discharges are made always to escape in the direction through the binding-cup B, and the refluent current of shocks to return by the opposite binding-cup A; and thus by this regular changing of the connection with the ends of the wire environing the electro-magnetic iron prong, the *initial currents* of electricity are always directed to move separately in one direction, and the *terminal* currents in the opposite direction, in the same manner as occurs between the exciting rubber and main conductor of the electrical machine, and between the zinc and copper of a galvanic battery.

The uniform propagation of electro-dynamic action, in an uniform current produces less violent effects on the nerves and muscles of animal bodies than oppositely directed alternate surges of electric action. By adding to the magneto-electric machine the apparatus of a "contact breaker," designed to interrupt very rapidly a continuous action, it is capable of producing such a "torrent of shocks," when the machine is of large size and the revolutions of it are rapidly accelerated, and such violent spasmodic contractions of the muscles of the hands, which grasp the handles, shown at H in the preceding figure, as to prevent the tortured experimenter from dropping them, to relieve himself of the agony which he thus involuntarily endures. By means of this machine, impulses of mechanical force may be propagated through the medium of electric matter to put in motion light machinery, as that for striking a bell, represented in the woodcut, with as much systematic regularity as the same impulses are commonly propagated through leather bands and iron shafts, for putting in motion mill machinery. The electro-dynamic action developed by combustion of food in the lungs, or of fuel in the steam boiler, may be propagated in the modified forms of animal motive power or steam power to operate the magneto-electrical machine. It puts in motion the electric matter naturally existing in connection therewith, and still further propagates the electro-dynamic action to operate the electro-magnetic machinery for moving the hammer to strike the bell.

Fig 64.



This experiment furnishes an impressive illustration of the wonderful available modifications of the employment of electric matter for continuously propagating impulses of mechanical force, even through two successive electro-magnets, with their respective environing wire coils. The action of the hand is shown to be as instantaneously propagated through the medium of electric matter to turn the machinery for striking the bell, as if the fingers were directly applied to lifting the hammer.

A description of the operation of the latter mechanism will be hereafter given.

These magneto-electric machines excite electric currents which resemble those of galvanic batteries, being sufficient to operate electric telegraphs, to decompose water, to deflagrate metals, to heat fine wires red hot, to fire gunpowder, and to precipitate gold and silver from their solutions in performing the process of electro-gilding and silvering. For the latter purpose it has been very successfully used instead of the galvanic battery in the workshops of Sheffield and Birmingham, as will appear by the following account.

For the purpose of exciting electricity for the practical operations of electro-plating and gilding, the magneto-electric machine is probably destined hereafter to supersede the galvanic apparatus, and all other kinds of electrical machines. Mr. Shaw gives the following account of a powerful magneto-electric machine constructed by Mr. Woolrich, and used in the workshops of Birmingham. The magnets are made to revolve by the motive power of the steam engines which impel the other machinery operated in these workshops. He states, "that although the first cost of the magneto-electric machine is certainly greater than that of the galvanic apparatus necessary to produce the same amount of power, yet the expenses of working it are incomparably less, being limited to the cost of a trifling motive power of a steam engine or water wheel. The economy of the magnetic machine for constant use must eventually gain for it a preference to the voltaic battery, where metal is to be deposited on a business scale. All the wear and tear of these machines is, of course, limited to the friction between the axis and its bearings, and to that between the contact breaker and springs."

The expense of the consumption of the materials of acids and metals is very considerable in ordinary galvanic batteries. Thus, as illustrated by Mr. Shaw, "in depositing zinc, as in zincing or galvanizing the surface of iron, supposing two cells, arranged as an intensity battery, to be employed, the quantity of zinc deposited would be just one half of that decomposed and consumed in the battery, and very nearly the same proportion would obtain in the case of copper. Hence, the expense of this mode of plating or depositing metals, as compared with the value of metals deposited, is very great." By the use of the magnetic machine, on the contrary, the expense of depositing is limited to the trifling cost of the motive power required to produce the rotation of the armatures of the apparatus.

So uniform is the current of electricity excited by this apparatus, and so regular is the process of the deposition carried on by means of it, that the mill governor, or regulator of the steam engine, serves actually to adjust it with such precision, that in a large establishment in Birmingham, where this process of electroplating is extensively carried on, the quantity of metal deposited as a coating is estimated by the time during which the machine is worked, "repeated weighings having demonstrated that the relation between the time of working and the quantity of deposited metal is sufficiently accurate."

From 300 to 400 ounces of silver per week have been deposited from sulphite solutions of this precious metal, by a magneto-electric machine, described by Mr. Shaw, when the armatures were caused to make 650 revolutions per minute.

In this magneto-electric machine, there are 8 armatures and coils, each of which become magnetic and cease to be magnetic four times in passing between the poles of 4 fixed permanent horseshoe magnets; and as the drum that carries them makes 650 revolutions per minute, there are, consequently, 20,800 changes per minute, from an unmagnetic to a magnetic state, induced in the 8 soft iron armatures; and an equal number of times per minute is a portion of the electricity naturally existing in connection with the wire coils expelled and returned.

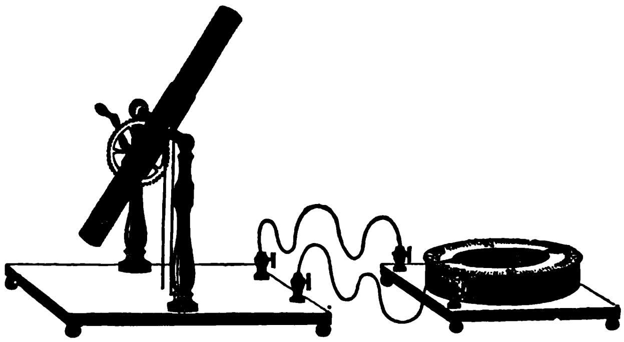
Thus, 20,800 electric discharges per minute are turned by the *pole changer* to flow off in one uniform direction along the conducting wire, to exert their electro-mechanical action, like the regular current of a galvanic battery.

During the most prolonged periods of the constant use of these magneto-electric machines, it is stated by Mr. Shaw that no appreciable diminution of their power has taken place, and no expense or delay is necessary to maintain them in good working order, such as is necessary whenever galvanic batteries are employed.

The use of this magneto-electric machine in the art of Electro-Plating, has been patented in England by J. P. Woolrich, an account of which is published in the 38th vol. of the Mechanics' Magazine.*

The circulation of electric currents, or the propagation of electro-dynamic action about the axes of portions of matter, has been shown in the preceding pages to be identical with the property of magnetism in bodies. A circulation of electric currents has also been shown to take place continuously about the earth's surface. Hence the earth itself is endued with all the properties of a huge magnet. In carrying out the principles of the excitation of electricity by the movements of bodies near magnets, it follows as a necessary deduction, theoretically, that we cannot move a mass of matter on any part of the surface of the earth without inducing simultaneous movements of electric currents therein. In consequence, however, of the comparative diffusion, and consequent action and reaction of the circulating terrestrial electric currents, it is a task requiring some nicety of arrangement of the freely movable parts of mechanisms, to demonstrate practically the truth of the preceding theoretical calculations. But this result admits of practical verification by the following experiment.

Fig. 65.



Deeming the line of dip of the dipping-needle to indicate the direction of the magnetic pole of the earth, and consequently to represent the position of the acting pole of a huge magnet, it only remains to employ a spiral coil of wire, mounted like a scale beam, as shown in the figure, so as to admit of being turned rapidly around, and of presenting first one end, and then the other to the action of the magnetic pole of the earth, to become a regular magneto-electric machine by means of terrestrial magnetism.

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* The subject of electro-gilding and plating will be presently considered in a distinct chapter.

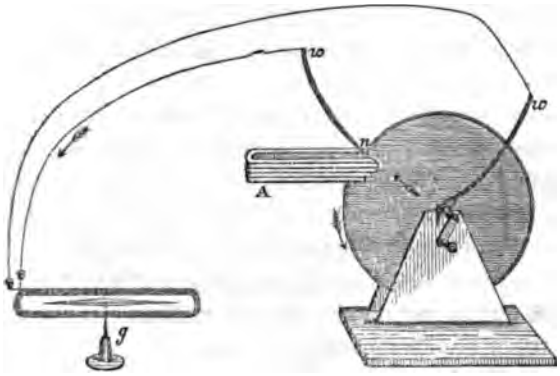
The hollow spiral coil is put in motion by a crank handle carrying a multiplying wheel, as shown in the figure, and is arranged in a north and south position, like a dipping-needle. As each end of the spiral coil successively approaches to the line of the dip of the dipping-needle, the electricity naturally existing in connection therewith is disturbed, precisely as when the revolving armature-coils approach the pole of a permanent magnet in the arrangement of the magneto-electric machines which have been described. And as the same ends successively recede from the strongest magnetic action of the earth, the disturbed electricity flows back to restore the equilibrium. Thus oppositely moving electric currents are induced in the revolving wire coil, the directions of their movements changing at the instant the coil passes the point of the line of dip of the dipping-needle.

These ebbing and flowing currents are separated by the pole-changer, arranged to act by means of springs pressing against the axis that supports the revolving coil, and soldered to conducting wires which severally convey the effluent discharges to one of the screw-cups on the base-board, and from the other cup, to complete the closed circuit. It is only necessary to connect these cups severally with the cups of a galvanometer, as shown in the figure, to cause the needle thereof to indicate, by its agitation and swerving, the presence of excited electric currents.

The galvanometer remains steadily swerved from its usual north and south position so long as the spiral coil is turned uniformly. By accelerating and retarding the velocity of its revolutions, a corresponding increase and decrease of electric excitation is indicated by the greater and less deflection of the needle; and by reversing the direction of the revolutions of the spiral coil, the direction of the deflection of the galvanometer needle becomes reversed.

Thus the earth itself, considered as a huge natural magnet, may be employed to serve as a substitute for an artificial magnet in inducing the excitation of magneto-electricity. But as it has been demonstrated that the phenomenon of terrestrial magnetism originates from the unceasing circulation of electric currents about its surface from east to west, we arrive thus at the final conclusion, that it is actually the presence of these electric currents which excites the electricity naturally existing in connection with the spiral coil of the above-described magneto-electric machine; and that the phenomenon of magneto-electric excitation is in reality no more than an excitation of electricity induced in one body by means of the presence of electricity excited in some approximated body, has been detailed at page 282, figure 56. Thus the mystery of magneto-electric excitation disappears, and the identity of electric and magnetic forces becomes more firmly established in our belief. We are led to conclude that the magnetic forces of the earth originate from the excitation of electric currents induced by the presence of the sun; and that the permanent magnetic excitation of natural loadstones derive their excitation indirectly from the sun, through the medium of these continuously excited terrestrial electric currents.

Fig. 66.



One of the simplest contrivances of mechanism for exhibiting he excitation of electricity by means of the movements of bodies ear magnets, was originally devised by Professor Faraday. He ixed a circular copper plate upon an axis with a crank handle, o be turned rapidly like a grindstone, with its rim between the wo poles of an U magnet, as exhibited in the cut.

To provide a conductor serving as a channel for the propagation of the electro-dynamic action, strips of elastic metal, *w*, *w*, were severally caused to press lightly in contact with the rim at *n*, and with the arbor. The rim of the plate was made smooth, and the parts brought into contact were amalgamated with mercury, to insure perfect contact. Connecting wires were soldered to the ends of the pieces, *w*, *w*, and extended to the mercury cups of the galvanometer, *g*.

When the copper plate was turned whilst the magnet A was withdrawn, the relative movements of the parts in contact with the piece of metal, *w*, induced a slight disturbance of the electric matter, as tested by the movement of the galvanometer needle, *g*. This disturbance soon ceased. Then the magnet A was arranged in its place, and a continuous deflection of the galvanometer needle became manifest on turning the circular plate. The movement of the needle was reversed by reversing the movement of the plate.

The electric matter existing in connection with the rim of the circular copper plate, and disturbed by the movement of it near the excited electric atmosphere of the magnet, A, was urged to propagate the electro-dynamic action in the direction indicated by the arrows, from the rim of the plate to the galvanometer, and from thence by a returning circuit to the axis and to the rim.

The mechanical impulses were continuously propagated through the medium of electric matter by the animal motive power applied to turn the crank to move the galvanometer needle on its pivot, without actual contact of the parts with the poles of the magnet; and hence it appears that electro-dynamic influence is exerted beyond the immediate surfaces of excited bodies, to disturb and put in motion the electric matter existing in connection with other bodies moved near them.

When this same copperplate was arranged by Professor Faraday to revolve with its plane at right angles with the line of dip of the Dipping Needle, the electric currents circulating from east to west about the earth's surface, and producing the phenomenon of terrestrial magnetism, served to excite an electric current precisely in the same manner as the artificial horseshoe magnet used in the preceding experiment.

On accomplishing this very remarkable result, Faraday remarks, "it was a striking thing to observe the copperplate becoming thus a new electrical machine; and curious results arise in comparing it with a common electrical machine. In the one, the plate is of the best non-conducting substance that can be applied; and in the other it is the most perfect conductor: in the one, insulation is essential; in the other, it is fatal. In comparison of the quantities of electricity produced, the metallic revolving plate does not at all fall below the glass one; for it can produce a constant current, capable of deflecting the galvanometer needle; whereas the latter cannot."

The intensity of these currents, however, are not sufficient for ordinary experimental purposes; but are found to be capable of traversing fluids, of producing shocks on the animal system, and, in the case of an electro-magnet, Mr. Faraday says, have even produced sparks. He continues, "Considering the universal diffusion of the action of the magnetic influence of the earth, it is a consequence which appears very extraordinary to the mind, that scarcely any piece of metal can be moved in contact with others, with different velocities, or in varying directions, without exciting an electric current within them." He suggests the probability, that amongst arrangements of the vibrating beams of steam-engines, and of the moving wheels of machinery, some curious accidental electric excitations may be found, producing effects which have never been observed; or, if noticed, have never as yet been understood. For, theoretically, he considers that even a ship or a boat passing on the surface of the water, in a northern or southern latitude, has currents of electricity running directly across the line of her motion; or if the water is flowing past the ship at anchor, similar currents must occur.

The swiftly moving leather bands employed to transmit motive power to mill machinery, if arranged to pass near adjacent bodies, will produce powerful electrical excitation, sufficient to cause sparks to dart off therefrom through a space of more than a foot.

Although the electricity excited by the mechanical friction of rubbers of electrical machines may have received the popular name of "Frictional Electricity," yet the preceding experiment shows that it is not from the absolute mechanical friction, and actual contact of the different kinds of matter of the materials employed, that electricity is developed. It is rather the action and reaction of the electricity naturally existing in connection with the rubber and rubbed body, which puts in motion the electric matter in the form of circulating currents. It cannot be supposed that the physical action of the matter of the rubber on the surface of the glass can scoop away the electric fluid existing in connection with the surfaces of either of the two bodies, as water deposited on a pane of window-glass can be scooped away by the friction of the hand. The intense pressure of heavy weights on a slip of gold interposed between two plates of glass, is inadequate to arresting the transmission of the electric action between them. Indeed, the plates may be shivered to pieces by the propagation of the electro-dynamic action between them, without arresting it.

It was the popular belief during many ages, that iron was the only substance susceptible of being acted upon by a natural magnet, or loadstone. The metallic substances, nickel, cobalt, and titanium, were subsequently discovered to be susceptible of magnetic action; but more recent discoveries made by Coulomb, Arago, Faraday, Barlow, and others, have experimentally demonstrated that all solid bodies, put in rapid motion near each other, are capable of exhibiting unequivocal indications of the action of impulses of mechanical force, even transmissible through intervening sheets of glass, characterized by the term "Magnetic." If various kinds of substances be affixed to the revolving arbor of a common turning lathe, and be thus caused to move by steam power, or water power, near a magnetic needle, with far greater rapidity than can be effected by manual dexterity, the magnetic needle is found to be immediately moved around on its pivot, and the deviation of the needle becomes greater in proportion as the motion of the approximated revolving body becomes accelerated. Indeed, if the rotations of the revolving body be sufficiently accelerated, the needle will finally begin also to turn around in the same direction with the revolving body.

It admits of demonstration that an equal reaction takes place, if the horse-shoe magnet be affixed to the arbor of the turning lathe, and caused to revolve rapidly near any body when reduced to a proper form of arrangement to become, like a delicately balanced needle, freely movable in obedience to the leas impulse of mechanical force brought to bear upon it.

In these experiments it is necessary to encase the bodies in glass, to protect them from the action of the currents of air put into motion by the movements of the rapidly revolving bodies.

The phenomenon of the attraction between the pole of a magnet and a revolving plate of copper or other substance, has been accounted for on the principle of the electro-dynamic action between the current of electricity excited by the presence of the pole of the magnet to flow from the centre of the circular plate toward the rim, as exhibited at figure 66, where a similar revolving copper plate actually constitutes an electrical machine. A reciprocal action of impulses of mechanical force are supposed to occur between this excited current and the pole of the magnet, which causes both the magnet and plate to revolve in the same direction.

It appears from the result of Mr. Harris's experiments, that by placing bodies susceptible of magnetic excitation, such as a plate of iron, between the revolving plate and the adjacent magnetic needle, serving as an intervening screen for intercepting the influence of the rotating bodies, the transmission of impulses of mechanical force through the medium of electric matter is arrested; in the same manner as a thick plate of iron intervening between two magnets intercepts their reciprocal action on each other.

By imparting extremely rapid revolving movements to a body near another at rest, very surprising results of electro-dynamic action become manifest. If a circular plate of metal be affixed to a spindle in a turning lathe, and caused to revolve several thousand turns in a minute, by water power, or steam power, such intense propagation of electro-dynamic action ensues as to exhibit all the phenomena of magnetic attraction and repulsion between bodies, where every other attempt developing magnetic phenomena in connection therewith may fail of success.*

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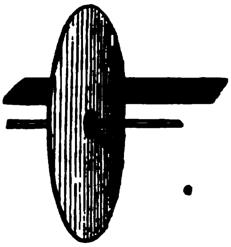
* See details of the phenomena of attraction and repulsion developed between revolving bodies and magnets, in Barlow's Treatise on Magnetism.

My attention having been directed to this subject many years ago, during a course of experiments, I caused a circular sheet of soft Russia iron, fixed on a spindle as shown in the figure, to revolve in a turning lathe, to which the most extreme velocity of rotation was imparted by water power, that the machinery employed was capable of sustaining.

Fig. 67.



So intense was the electro-dynamic excitation produced by the rim of this piece of sheet iron, that a bar of steel, brought gently against it, was rendered almost instantaneously red-hot about the parts in contact with the revolving disc. Yielding to this intense excitation, the cohesive forces of the hardest steel files became speedily counteracted, so as to permit the edge of this disc of soft iron to traverse freely through its unresisting substance, as if it were softened wax. The workmen were thus enabled, without apparently affecting the sheet iron, to cut out an entirely new set of teeth from a heavy circular saw-plate of cast steel.

The cohesion and temper of the steel is instantaneously counteracted by the powerful electro-dynamic impulses propagated by this rapid movement of the revolving body in immediate proximity and contact with it; and a considerable mass of the metal was thus kept red-hot. When it is considered that a powerful galvanic current is required to heat a piece of wire, it may be estimated that a propagation of electro-dynamic action superior in intensity to that of the most powerful galvanic battery is developed by the rapid movement of this revolving plate. Scores of combined frictional electrical machines would not develope a sufficiently intense excitation to produce the preceding result of electro-dynamic action.

On bringing the same rapidly revolving disc of sheet iron into contact with pieces of marble, which I had hoped also to cut through with facility, and thus to abridge the tedious process of *sawing* this refractory material, I found that little or no impression was made thereon by this process.

The polarization of the atoms of the mass of marble is not accomplished, as it is in the mass of steel. This experiment demonstrates that the phenomenon of cohesion of the atoms of a cast steel file, is contingent on the electro-polarization of the particles. Were it practicable to affect similarly the electro-polarization of marble and other similar substances, they might doubtlessly be severed with facility.

All the preceding details of the continuous propagation of electro-dynamic action between portions of terrestrial matter, have been traced to the relative movements of approximated bodies. It has been shown that *there cannot occur the movement of one body near another without disturbing the electrostatic condition of both bodies, and without producing the consequent development of electro-dynamic action.* Wherever approximated portions of matter are in motion, the propagation of impulses of mechanical force through the medium of electric matter must necessarily ensue; and as the science of astronomy teaches us that all the worlds of our cluster in the free space of the heavens are in a state of inconceivably rapid motion, the preceding experiments afford conclusive evidence that the original design in imparting rapid motion to these approximated portions of matter must have been to sustain a continuous electro-dynamic excitation. Such rapid movements of huge masses of matter near each other cannot fail of inducing powerful disturbances of their electrostatic conditions, and a consequent development of electro-dynamic impulses, not only between the masses themselves, at sensible distances, but also between all the component atoms of these masses, at insensible distances, recognizable by finite intelligence, under the various names of *attraction*, *repulsion*, *polarity*, *gravitation*, *cohesion*, *magnetism*, *chemical action*, *light*, &c. Indeed, the continuous excitation of the great central orb of solar matter originates from, and is sustained by, the rapid movements of the orbs of matter revolving about it in the space of the heavens.

It is sufficient for our present purpose to establish the law, that electro-mechanical forces producing the phenomena of attraction, repulsion, and polarity,—identical with "magnetism," "gravitation," &c., must necessarily be co-extensive with the movements of matter in the space of the heavens.

EXCITATION OF GALVANIC ELECTRICITY, OR THE PROPAGATION, THROUGH THE MEDIUM OF ELECTRIC MATTER, OF MECHANICAL ACTION BETWEEN ATOMS AT INSENSIBLE DISTANCES.

In treating of mechanical, or machine electricity, all the available modes of applying motive power to put the parts of the machines in motion have been traced to the electro-dynamic action of the sun on terrestrial matter, which produces food and fuel, and the water and wind powers which mankind employ, to propagate impulses to turn their machinery.

In treating of chemical or galvanic electricity, it remains to be shown, that a similar principle of the propagation of the electro-dynamic action of the sun is effected through the medium of the fuel burnt in smelting furnaces, to reduce metals to the constrained electro-polarized conditions, in which they are employed to excite galvanic electricity "chemically."

The metal, zinc, is commonly selected for use in the cells of galvanic batteries; and to this metal, more particularly, will our attention be directed. It will serve as a type of the similar employment of all other kinds of metals for this special purpose.

The excitation of mechanical electricity originates from the relative movements of portions of matter at sensible distances. In the excitation of galvanic electricity, the same phenomenon originates from the relative movements of atoms at insensible distances from one another.

The propagation of impulses of mechanical force between atoms of different kinds of elementary matter at insensible distances from one another, producing their movements toward and from each other's centres, has been popularly ascribed to a distinct agency of nature denominated "chemical action," as distinguishable from mechanical action, which is supposed to take place only between portions of matter at *sensible* distances. It is manifest that chemical action is only a modification of mechanical action; for a difference of distance cannot change the nature of an impulse of mechanical force; whilst the various modifications of these impulses between each of the several kinds of elementary atoms do not affect this inquiry, any more than the various modifications of the powers of each class of animals affects the nature of an impulse of force propagated by animal motive power.

In treating of the organic formations of food and fuel, it has been shown that they represent constrained static conditions of groupings of atoms; and that on every change of groupings of atoms from one static condition to another, an electro-dynamic action is propagated to surrounding elementary atoms.

These changes of the groupings of atoms represent the relative movements of minute portions of matter at insensible distances, instead of masses of them of appreciable magnitudes at sensible distances, which have just been under consideration.

As there cannot occur movements of appreciable portions of matter at sensible distances without propagating mechanical action through the medium of electric matter, it follows from analogy that a similar propagation of mechanical action must be developed by every movement of inappreciable portions at insensible distances. The differences of magnitude and of distance cannot affect this general law of the identity of mechanical impulses. The excitation of Galvanic electricity will therefore be considered as identical with mechanical electricity, the former being developed between atoms,—the latter between masses.

There appear to have been advanced at different times three prominent theories of galvanic electricity.

The first was promulgated by Volta, who ascribed electrical excitation to the contact of different bodies, and hence his theory has been denominated "the Contact Theory," as has been before stated.

The second theory ascribes galvanic excitation to chemical action; and this theory has received the name of the "Chemical Theory."

The fact that the rapidity of the oxidation of the zinc keeps pace with the rapidity of the electrical excitation, led Creve and Fabroni first to suggest that oxidation, or, in other words, chemical action, is the primary cause of the development of electricity.

This opinion has been advocated by Wollaston, Parrot, and others. Professor Faraday affirms that "galvanic electricity is entirely due to chemical action, and is proportionate to the intensity of the chemical action concerned in its production, and in its quantity to the quantity of matter which has been chemically active during the evolution."

There appears to be an inconsistency in this opinion with another expressed by the same distinguished philosopher, affirming "that the forces termed Chemical Affinity, and Electricity, are one and the same." If these two opinions be collated, it would be inferred that galvanic electricity is entirely due to itself, or self-originating.

A third electrical theory, advanced by Sir Humphrey Davy, appears to combine the leading principles of the two preceding theories. He adduced many experimental proofs of the truthfulness of Volta's supposition of the disturbance of the electric equilibrium of the two different kinds of elementary substances by their contact, without any chemical action taking place between them; whilst he admitted, in accordance with Wollaston's suggestion, that although chemical action increased and sustained the excitation, yet "it is not the prime mover of the electric current." He supposed that "the electric excitement was begun by metallic contact, and maintained by chemical action."

In his paper published in the Phil. Transactions in 1826, page 389, Sir H. Davy observes, that "chemical and electrical attractions are produced by the same cause; acting in one case on *particles*, in the other on masses of matter; and that the same property, under different modifications, is the cause of all the phenomena exhibited by different voltaic combinations."*

Becquerel concludes his observations on this subject, by stating, that although in nearly all cases of the contact of different bodies, chemical action may occur, nevertheless, in the present state of our knowledge, we are not prepared to abandon the original contact theory of Volta.

In tracing out the propagation of mechanical action through the medium of electric matter, we shall recur to the primary reduction of the metallic zinc from its natural static condition of grouping as an *ore*, to its constrained static condition of groupings, or rather of polarity, as a pure metal.

The natural polarized condition of the atoms of zinc in the earth, is in groupings with atoms of oxygen, carbon, sulphur, and silicon, constituting *ores*, as before stated. Unlike gold, platinum, and copper, zinc is never found in the natural static condition of a pure metal. To obtain a mass of pure glittering zinc is therefore a work of art. The ore is to be first procured from its localities beneath the earth's surface, in the form of grayish crystals, either imbedded in solid rocks, or in a comminuted earthy state. The ore is placed in covered crucibles, and exposed to the excitation of heat in furnaces. The atoms of pure metal are reduced to the state of vapor, as in the process of the distillation of alcohol and mercury, the separated pure metal being distilled and collected in a receiver. By this process of smelting the ores, ten pounds of carbon or coal are caused to recoil from their constrained static condition of fuel to their natural condition of carbonic acid gas in the process of combustion, to propagate a sufficient electro-dynamic action to reduce one pound of atoms of zinc to the constrained static condition of a mass of pure glittering metal.

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* The reader will find in the 1st, 2d, and 5th volumes of Becquerel's Treatise on Electricity, an elaborate investigation of the comparative merits of the contact and chemical theories of Electricity.

The smelting of zinc requires a more prolonged excitation of heat and greater combustion of fuel than any other kind of metal. The electro-dynamic action of the sun expended in reducing ten pounds of carbon from its natural static or polarized condition of carbonic acid gas to the constrained static or polarized condition of organic formations of fuel, must be further propagated in the smelting furnace to the atoms of the ore, to separate them from their natural groupings with oxygen, carbon, sulphur, and silicon.

With these facts before us, we may readily comprehend the process of smelting zinc, and all other ores of metals, by the combustion of fuel in furnaces, philosophically speaking, to be effected by an artificial propagation of the electro-dynamic action of the sun through the medium of the groupings of atoms of fuel; which, on recoiling to their natural polarizations of carbonic acid gas in the smelting furnace, propagate electro-polarization to the atoms of the zinc.

Although pure zinc is commonly reduced to its constrained polarized condition by the combustion of coal as fuel in the smelting furnace, yet by means of the artificial appliances of convex lenses and concave mirrors, this result admits of being thus more immediately accomplished by the direct electro-dynamic action of the sun.

One pound of this metal thus represents ten pounds of coal, or other equivalent fuel. Consequently, unless one pound of zinc consumed in the battery cells prove equivalent to developing more effective impulses than ten pounds of coal consumed in the furnace of a steam engine, employed to turn magneto-electric machines, there would be no gain in favor of consuming zinc in the galvanic battery instead of coal in the furnace of a boiler, as a mean of propagating the electro-dynamic action of the sun in the modified form of electro-motive power. This calculation is to be taken into account in all estimates of the economy of employing electro-magnetic engines as substitutes for steam engines.

The polarization of the atoms of pure zinc is therefore analogous to that of the atoms of organic formations of food, fuel, vapor of water in the modified form of steam, of thunder clouds, and of jets issuing from a hydro-electrical machine, of pure hydrogen gas, &c., as has been before recapitulated. On the recoil of the zinc from this constrained polarized condition to its natural polarized condition, it might be rationally anticipated that electro-dynamic action in the variously modified forms of electric sparks and flashes, of heat, light, and mechanical impulses, must become developed.

That the excitation of a galvanic battery does not originate from this *chemical decomposition* of water, but on the contrary in despite of it, is manifest from the fact, that a portion of the electro-dynamic action developed during the recoil of the zinc, is expended in producing the chemical decomposition of the water. The pure hydrogen of the decomposed water represents the polarized static condition of the zinc and fuel, from which it has received the propagation of the electro-dynamic action producing its polarization. The polarized hydrogen becomes fuel.

Before investigating the facts of the excitation of chemical or galvanic electricity by the decomposition of metals, these preliminary views of the materials employed are absolutely necessary for a just comprehension of the subject. It is to be clearly understood that the process of smelting metals is an indirect mode of propagation of the electro-dynamic action of the sun by the combustion of fuel, as before stated. The Organic action is thus brought antagonistically to overpower the Inorganic action, or natural polarization of the atoms of zinc in combination with atoms of oxygen, carbon, sulphur and silicon. Under favorable ircumstances of the juxtaposition of these atoms in the battery ell, the atoms of zinc recoil to their natural polarizations,—the Inorganic reaction prevailing in turn over the Organic action. This phenomenon is presented to view in the decomposition of he zinc in the battery cell.

The separation of the atoms of metals from their ores is strictly a mechanical process, accomplished by the propagation of mechanical impulses. In every case of the propagation of mechanical impulses there must be an action and reaction. The continuous propagation of the electro-dynamic action of the sun, modified by the groupings of atoms into the mechanisms of the living organs of plants, constitutes the Organic action. The same electro-dynamic action of the sun, modified by the groupings of atoms into the molecules of the sixty different kinds of elementary substances, constitute the Inorganic action. These two oppositely modifying influences propagate the electro-dynamic action unceasingly between atoms at insensible distances, and masses at sensible distances, as has been premised, producing the Polarizations which have been detailed, and the consequent phenomena of Attraction and Repulsion.

When the Organic action prevails over the Inorganic action, it produces a polarization of a mere temporary and constrained character. The Inorganic action restores a more permanent or natural polarization to the same atoms of the organic elements, which are subjected to these alternate changes of polarizations, as the one or the other action becomes paramount.

Thus, the polarization artificially imparted to zinc by the processes of the smelting furnace resembles the temporary deflection of an elastic spring, which, when relieved of the deflecting power and allowed freedom to recoil to its natural position, reacts with precisely the same power as was previously expended, or employed to deflect it.

The character of the organic formations of fuel, burnt in smelting furnaces, is imparted to all metals smelted by the combustion thereof. Indeed, even the unsmelted, as well as smelted metals, themselves really constitute fuel when reduced to thin sheets, in contact with pure oxygen, if subjected to electro-polarization between the poles of a battery. They burn with a most dazzlingly brilliant light and intense development of heat.

This fact demonstrates that the final natural inorganic polarization, even of gold and platinum, is that of an ore.

To such intensely constrained polarized conditions are the atoms of the pure metal potassium reduced, when artificially separated from their natural groupings with atoms of oxygen, that they will recoil even when thrown into water, propagating the electro-dynamic action in the modified form of flashes of light, of heat, of electricity, and impulses of mechanical force; and exhibiting the phenomena of combustion more vividly than any other kind of fuel.

If the pure metallic zinc be similarly immersed in the same vessel of water, the electro-dynamic action is as certainly, although less vividly developed. The recoil being more gradual to the natural static condition of an oxide or ore, a sufficiently intense development is not propagated directly to the material electroscopic nerves of sentient beings, to become recognizable as a perception of light, of heat, and of other phenomena of combustion.

The recoil of the zinc is rendered more rapid, by adding to the water, in which it is immersed in the battery cell, a supercharge of atoms of oxygen, in the form of *acids.*

Under these circumstances, the electro-dynamic action becomes more palpably developed in the peculiarly modified form denominated "galvanic electricity," instead of "combustion," as occurs in the air. The philosophy of the employment of acids in battery cells, is therefore founded on the principle of furnishing a more ready supply of atoms of oxygen to become polarized with the atoms of the metals.

The fact, that the contact of metals developes electrical excitation, as affirmed by Volta's theory, is in accordance with the preceding law (page 311), that there cannot be a movement of one body near another without disturbing the electric matter existing in connection with both bodies. But this development is only continued whilst the two bodies are in motion toward or from each other. When the movements of the bodies are arrested, the further electric excitation is simultaneously arrested. Whereas, the development of galvanic excitation is continuous after contact of the two elements brought together in the battery cell.

The "contact of metals" is merely a mechanical effect produced. It cannot, therefore, be an originating cause. Every workman who wields a hammer to drive a nail is aware that mechanical contact is a mode of propagating action, and consequent motion, to matter;—not of originating action or motion.

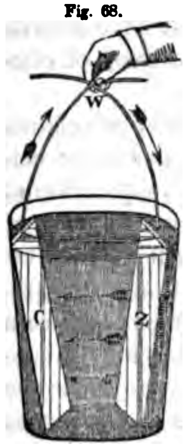
The mechanical contacts of the metals employed by Volta, were produced by the motive power developed by combustion in his lungs of food organized by the previous mechanical action of the sun as before repeatedly stated. If this distinguished philosopher, in framing his Contact Theory, had extended his inquiry one step further to the question of the origin of the cause of motion producing the contact of the metals, he must have arrived at the unavoidable conclusion of the existence of a cause of electric excitation precedent to the Contact.

The continuous recoil and consequent continuous relative movements of the atoms of zinc and acidulated water in the battery cell, are necessary to produce the continuous propagation of electro-dynamic impulses which represent, figuratively, a current of *electrical forces.* The term "electric current" will be hereafter used briefly to designate the continuous propagation of electro-dynamic action, without reference to the fact whether there be a continuous stream of successive portions of electric matter, a continuous vibration of the same portion of matter to propagate the action, or an extension of the polarization of lines of contiguous molecules.

With these preliminary facts established, we are prepared to take a philosophical view of the true nature of the functions of a galvanic battery. We are first to regard the plate of zinc as mechanically representing the organic grouping of atoms of the fuel, burnt in the smelting furnace to reduce it to the constrained condition of a wound-up watch-spring by means of the artificial propagation of the electro-dynamic action of the sun, through the medium of the fuel employed. We are next to regard the animal motive power originating from the same mechanical source, applied to moving the plate of zinc into contact with the atoms of water in the battery cell; and if acid be superadded to this water, then we are further to look to the action of the sun propagated to produce vegetable acids, or to the combustion of fuel similarly employed in laboratories to reduce sulphuric and other acids to their constrained polarized states. Then, by applying the general law, that there cannot be a movement of one portion of matter near another, or a change of their polarizations, without developing a resultant electro-dynamic action, we are prepared to anticipate theoretically all the phenomena of "galvanic excitation."

When a piece of zinc is dropped into a vessel containing acidulated water, bubbles of gas are seen to issue from the metal, and the electro-dynamic impulses are propagated therefrom in every direction. By these counterbalanced opposite directions, the impulses neutralize each other's actions and reactions. Consequently, no decided electro-dynamic action is perceptible. This experiment has been repeated thousands of times before the discovery of the galvanic battery arrangement, without developing electric excitation. But if a plate of copper or platinum, as at C, in the figure annexed, be placed opposite to the zinc, Z, the impulses are determined through the water to the atoms of the copper plate, in one common specific direction. As the latter metal is in a more natural polarized condition, it does not propagate a reaction in an opposite direction to the arrows shown in the liquid; as would be the case were a similar piece of zinc immersed in the acid in place of C, opposite to Z.

Fig. 68.



In the latter case, the electro-dynamic impulses between the two plates would be propagated reciprocally between each other, and a consequent counterbalanced neutralizing action and reaction would occur. This fact demonstrates the necessity of the employment of a metal in a natural polarized condition, such as platinum, gold, or copper, which will not react to counterbalance the electro-dynamic impulses of the recoiling atoms of the zinc; but, on the contrary, will serve, like the row of pointed wires on the frictional electrical machine, to receive and transmit the electro-dynamic action in one determinate direction. Although the plate C does not react upon Z, yet there must be somewhere a reaction. For in this case, as in every other case of mechanical action, science teaches us that there must be an equal reaction in an opposite direction. Hence, whatever may be the intensity of the action from the plate Z to C, here must be propagated an equal simultaneous reaction from C o Z, as is also denoted by the two oppositely directed upper rrows.

This simple fact of the inseparable development of precisely qual and oppositely directed impulses in this, as in every other nstance of electric excitation, constitutes the strongest possible roof of the identity of electrical and mechanical action and reaction, as governed by the same unfailing general law. This excitation may be denominated "negative" and "positive," and asribed to "two different kinds of electric fluid," at the pleasure f theorists; yet it can be no more nor less than mechanical action and reaction.

This form of construction of a battery was one of the earliest kinds originally adopted by Volta, who arranged several of them n a circle, with the copper of one connected by a wire with the inc in the next cell. This form of arrangement he denominated "*couronne des tasses*"—a crown or circle of cups.

During the recoil of the zinc in the battery cell, the Inorganic reaction overpowers the Organic action. A portion of the resultant force is expended to reduce the atoms of hydrogen, forming a constituent part of water, from their natural polarized condition to the constrained polarized condition of a pure gas. The remainder of the resultant action is propagated through the medium of electric matter to other adjacent matter, producing the phenomenon popularly recognized as the "Excitation of Galvanic or Chemical Electricity."

DIFFERENT KINDS OF GALVANIC BATTERIES.

As the degree of energy of electric excitation essentially depends on the regular continuous recoil or "chemical decomposition" of the groupings of atoms of zinc from their constrained static condition to the natural static condition of oxides or of ores in the battery cell, the history of the successive improvements of galvanic batteries affords an instructive account of the gradual surmounting of the difficulties successively overcome.

To sustain a continuous and rapid recoil of the groupings of atoms of the zinc, it is manifest that free access of an uniform supply of the atoms of oxygen of the acidulated water must be provided for. In the practical operation of the original galvanic batteries, composed of plates of zinc immersed in acids, it was found that three distinct obstructing causes impeded the uniformity of the electrical excitation, viz.: 1st, the accumulation of a coating of bubbles of hydrogen at the surface of the copper plate forming a non-conducting screen; 2d, the accumulation of the earthy matter of the oxide in the form of a crust or scale on the surface of the plates of zinc, serving as a coating to intercept the further access and grouping of the atoms of oxygen of the acids with those of the zinc; and 3d, the gradual exhaustion of the excess of atoms of oxygen, constituting the strength of the acids in their grouping with those of the zinc.

The atoms of hydrogen separated from their union with those of the oxygen in the composition of water, are seen to gather thickly in bubbles adhering to the surface of the platinum or copper plate, so as to coat its surface. Then they commence rising, and burst at the surface of the acid solution.

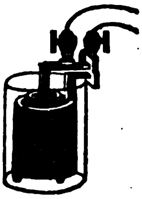
The accumulation of these bubbles on the surface of the plate, indeed, sometimes forms such a non-conducting coating as to prevent the plate from performing the designed functions of collecting and determining the electro-dynamic impulses in one specific direction.

Availing himself of the plan of arranging rows of pointed wires in electrical machines for determining more freely the propagation of electro-dynamic action, Mr. Smee contrived to impart to the surface of the revolving plate a similar system of the sharp points of crystals of metals artificially formed thereon. He used plates of silver on which platinum on angular points of crystals are deposited.

A wooden cross was used to sustain the pairs of metal plates, to each one of which screw-cups were soldered thereto, to insure contact.

As the natural polarized condition of the atoms of copper plates is subject to be disturbed by the contact of acid solutions, and reduced to an oxide, like the metal zinc itself, in which cases counteracting neutralization of the electro-dynamic action of the battery is produced, Mr. Smee introduced the use of platinum as a substitute for copper.

Fig. 70.



Smee's battery was a great improvement in the constancy of the development of effective electric excitation, it being capable of sustaining "active operation for six, eight, ten, or more days, when a sufficiency of acid is applied to it," as stated by Mr. Noad. He further states that "it has done a greater amount of work than all the other batteries put together."

To obviate the disadvantage of a necessity of supplying fresh acid occasionally, as that in the cell becomes exhausted, recourse was had to the use of a quantity of acid crystals placed in the cells to become dissolved gradually, to furnish an uniform supply, for sustaining "constant batteries."

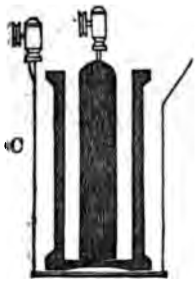
To provide a reservoir of acid, a quantity of the sulphate of copper or blue vitriol of commerce is put into the battery cell with the acid, in charging the battery. The atoms of zinc, in recoiling to their natural static conditions, become grouped with the atoms of the sulphur and oxygen of the sulphuric acid. And the atoms of oxygen previously united with those of the copper, become united with the atoms of the hydrogen set free by the decomposition of water, so as to reproduce water. No appearance of hydrogen, therefore, is perceptible in the cell of this kind of battery. The accumulation of bubbles of hydrogen is thus obviated.

It is manifest that this plan for facilitating the recoil of the zinc, must develope more efficient electro-motive power; because there is here avoided the expenditure of electro-dynamic action, which is unavailably propagated in reducing the atoms of hydrogen of water from their natural polarized state to a constrained polarized state of a pure gas, as has been previously recapitulated. But this advantage is purchased at the expense of previously reducing the copper from its natural polarized condition of a pure metal to the constrained polarized condition of groupings with atoms of sulphur and oxygen in the form of transparent crystals of blue vitriol.

The sulphate of copper battery, originally employed by De La Rue, is thus more effective than Smee's battery; but it is found that although the coating of bubbles of hydrogen is avoided, and a constant supply of acid is attained, yet the zinc becomes speedily coated with a scale of oxide, and with a coating of revived bright particles of copper. The only remedy for this difficulty is to withdraw the zinc plates and to scrape off the brown oxide and particles of copper adhering thereto. The crust of copper as well as that of oxide, accumulated on the plate of zinc, conspire to diminish the rapidity of the recoil of the zinc, and the consequent propagation of electro-dynamic reaction therefrom.

The preceding defects have been, in a great measure, obviated by the ingenuity of Becquerel and Daniell, by protecting the zinc from the immediate access of the particles of copper and oxide. The zinc is inclosed within some porous substance capable of intercepting the deposit of the obnoxious particles, as shown in the figure. In the sectional view given, C represents the outer copper vessel, serving both for containing the acid solution of sulphate of copper, and also to perform the function of a conductor. Within the copper cell is placed another smaller cell, made of porous earthenware, thus forming two distinct cells. The outer cell is used for containing the sulphate of copper, and the inner cell some other saline solution. The intervention of the porous vessel serves to keep the amalgamated zinc clean and bright for a longer time, and to impart to this battery a superior character as a "constant battery."

Fig. 71.



The supply of sulphate of copper is furnished from a quantity contained in a muslin bag immersed therein, or from a deposit of it in the projecting nose of the outer copper vessel, as shown in the figure.

Daniell recommends a mixture of eight parts of water and one of sulphuric acid, which is to be saturated with sulphate of copper, for the supply of the outer copper cell, the internal porous earthen ware tube being filled with the same acid mixture without copper. The porous tubes should be well soaked in dilute sulphuric acid for an hour or two before being used; and after their removal from the battery, they should be repeatedly rinsed or soaked for some time in warm water to dissolve all the metallic salts from the pores; otherwise they will become broken by the crystallizations of salts in the pores, like that of water crystallizing or freezing in bottles.

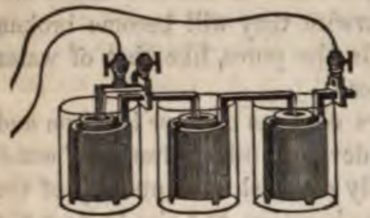
The zinc of commerce always contains more or less iron and other foreign substances, which develope minor circuits of counteracting currents, and essentially diminish the intensity of the excitation. To obviate this disadvantage, and also to keep the zinc plates clean and bright, Mr. Sturgeon originally applied a coating of mercury to the surface of the zinc. This coating serves also to prevent the wasteful recoil of the atoms of zinc to their natural polarized conditions whilst the battery is not in action by the connection of the battery circuit.

This coating of mercury produces a result very different from what might be theoretically anticipated; for, instead of protecting the zinc by preventing the immediate contact of the acid, it is found that the oxidated particles of zinc are withdrawn from beneath it, leaving the surface of the mercury clean and bright. The zinc is more rapidly decomposed by this arrangement, instead of becoming protected from further action of the acid, as occurs when a crust of oxide becomes deposited thereon.

With this improvement the battery becomes far more "constant" than before, being capable of propagating a nearly unvarying electro-dynamic action during several days in succession, care being taken to provide an adequate supply of the crystals of blue vitriol, and to stir the solution in order to diffuse it equally throughout the external cell. For purposes requiring an uniform electro-dynamic action to be continuously sustained, as in the process of electro-plating metals, this form of battery is advantageous.

A still further improvement in the use of acids employed in battery cells, was made by Bunsen and Groves, by using nitric acid in contact with the platinum plate, contained in the porous earthenware vessel, shown in the preceding figure. Sulphuric acid, diluted with four or five parts of water, is poured into the outer glass vessel containing the zinc cylinder, which has a division in it to admit the acid freely both to the internal and external sides.

Fig. 72.



Bunsen's battery is very generally used on the continent of Europe. Cylinders of carbon, in contact with the nitric acid, are substituted for platinum, the carbon being moulded to an iron tube by coking pounded bituminous coal therein. By soaking the coke in sugar, and calcining it a second time, great compactness is given to the cylinder. The comparative superiority and effectiveness of the nitric acid battery as compared with the preceding batteries, serve beautifully to illustrate and trace out the propagation of electro-dynamic action between groupings of atoms, and the resultant forces developed.

Nitric acid is composed of the extraordinary and unstable polarized groupings of five atoms of oxygen to only one of nitrogen. This excess of atoms of oxygen is therefore very readily available to combine with all other groupings of atoms, reduced to a constrained static condition for a want of this supply of atoms of oxygen, in connection with which they exist in a natural polarized condition, after they are brought into connection with them. Whilst the zinc is recoiling to its natural static condition in the outer vessel, the atoms of hydrogen, set free and reduced to the constrained polarized condition of a pure gas, are afforded extraordinary facility for simultaneously recoiling to their natural static condition of water by becoming grouped with the surcharge of atoms of oxygen in the nitric acid. At the same time the atoms of this nitric acid are prone to recoil from the constrained polarized condition of a grouping of 1 atom of nitrogen with 5 of oxygen, to a protoxide, constituting a grouping of 1 atom of nitrogen to 1 atom of oxygen; and more particularly to its natural static condition of grouping with oxygen in the ratio of union of the atmospheric air, in the proportion of nearly 3 atoms of nitrogen to 1 of oxygen.

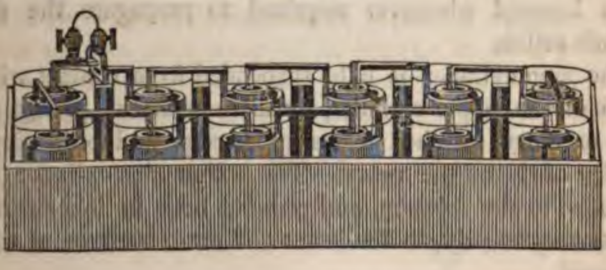
The atoms of zinc in the preceding arrangement, so far from having to expend a portion of the electro-dynamic action propagated during their recoil to reduce hydrogen to the constrained condition of a pure gas, is actually aided in accomplishing the decomposition of the water by means of the co-operative tendency of the nitric acid, similarly to recoil. By this double reaction of the zinc and nitric acid, the surprising development of eight or ten-fold more effective electro-dynamic power is the resultant reaction, as compared with the battery of Smee.

It is to be remembered, however, in this case, as in that of the employment of the crystals of the sulphate of copper similarly reduced to this constrained static condition previously to being used in the battery, that this advantage is purchased by the preliminary propagation of electro-dynamic action in the laboratory to reduce the nitric acid to its powerfully constrained static condition of groupings.

Pure water admits of being artificially reduced to a very constrained polarized condition of groupings with a surcharge of oxygen, constituting the peroxide of hydrogen (hydrogen 1, oxygen 2), from which the oxygen is more freely evolved than from nitric acid. It appears possible that this compound of peroxide of hydrogen might be efficiently employed as a substitute for the nitric acid in the interior battery cell, without the annoyance of the pernicious fumes arising from nitric acid; indeed, it might act explosively evolved on contact with the battery plates.

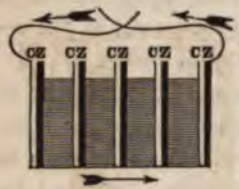
In the figure is represented a series of a dozen pairs of Grove's battery in the order in which they are commonly arranged.

Fig. 73.



One of the earliest modes of arrangement of the plates of galvanic batteries in a series was invented by Cruikshanks, and which, from its compactness, is still in use. The copper and zinc plates are soldered together in pairs, as it were back to back, each zinc plate being made to face an opposite copper plate as shown in the figure.

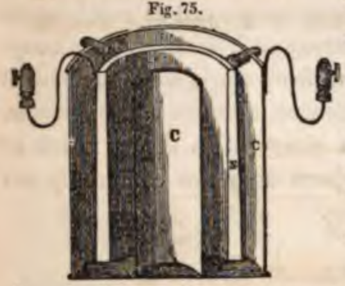
Fig. 74.



Each plate is inserted in a groove, in a trough, and serves to form a water-tight partition, dividing the trough into an equal number of cells with the pairs of plates intervening between them. This kind of battery has been in very general use in lecture-rooms.

An improvement in the construction of the cell of the battery was made by Wollaston, founded on the principle that if the plate of zinc be immersed in acid, with both surfaces facing approximated copper plates on each side, that electro-dynamic impulses might be simultaneously propagated from both surfaces of the zinc. To obtain this advantage in a single cell the zinc is cast into a cylindrical shape, a little smaller in diameter than a copper vessel containing the acid into which they are to be immersed. To present a copper surface against the interior surface of the zinc cylinder, Z, a smaller cylinder of sheet copper, of which a sectional view is given at C, is brazed to the copper bottom of the vessel. The space between the two copper cylinders, C C, receives the water or acid, into which the zinc cylinder is lowered whenever required to propagate the electro-dynamic action.

Fig. 75.

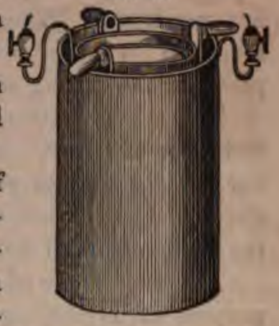


The zinc cylinder is held suspended from contact with the bottom of the copper cylinder, by three insulating prongs of dry wood or ivory, attached to its upper edge, and projecting over the edge of the copper vessel. The hollow zinc cylinder is thus suspended in the solution, and presents both its inner and outer surfaces respectively, to the inner and outer surfaces of the copper vessel.

To form a ready connection of the conducting wires with the zinc plate and copper, a screw cup, N, is soldered to the zinc plate Z, and a similar cup is affixed to the copper vessel, the whole apparatus appearing as shown in the wood cut 76, when ready for use.

Where several cells are combined together, they are reduced flattened cases, and affixed to an arbor, with machinery ade- ate to dipping them all simultaneous- into the acid, and to raising them refrom when not in use.

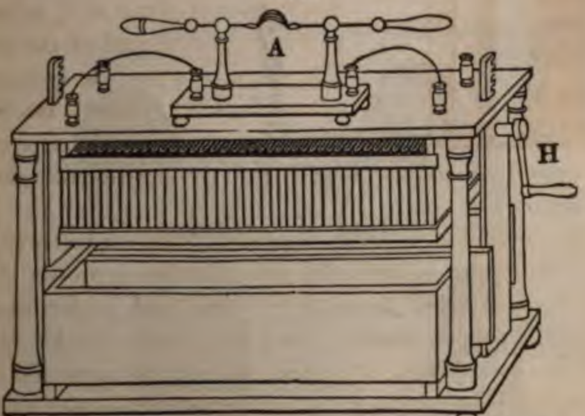
Fig. 76.



Very effective batteries have been med by filling battery cells with sand turated with acids.

Where a great number of pairs of ates are required to employ their com- ned powers of action, they are com- ctly arranged in battery form as shown the figure (77). The plates are sus- ended stationarily, and the troughs below, filled with acids, re raised up to submerge the plates therein by means of the wo racks shown at each end of the apparatus. Small pinion heels affixed to a shaft turned by the crank handle, H, work ato the teeth of these racks, and elevate or depress the troughs t the pleasure of the operator.

Fig. 77.

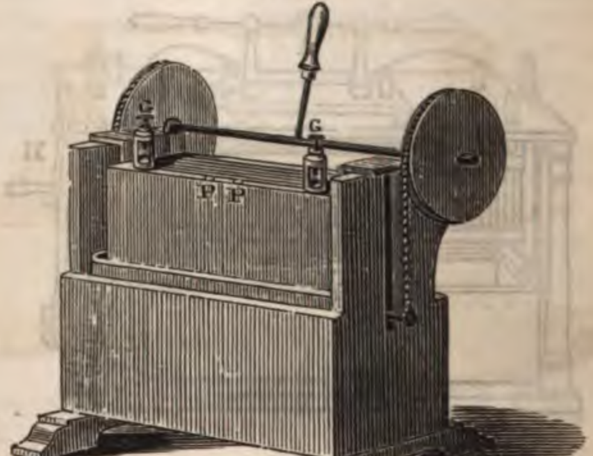


In the battery represented in the figure there are two distinct ies of 50 pairs, each connected with two of the four cups on table above the battery. By this arrangement the whole y be used as a single series of one hundred pairs, or as a battery of fifty pairs of double size, accordingly as the respective connections are formed with the binding cups. There being two separate troughs, only half of the battery may be used by removing one trough. These numerous pairs more particularly exhibit the phenomenon of electric flame between two separated points of the battery circuit, as shown in the wood cut.

To produce extraordinary electro-dynamic action in the modified form of "heat," or "caloric," galvanic batteries, of a peculiar arrangement of plates, have been devised. Dr. Hare has distinguished himself by successful experiments for developing the phenomenon of heat by means of electrical agency.

The usual mode of arrangement of batteries designed for the purpose of developing the phenomenon of heat, is in several pairs of very large sheets of zinc and copper, all the sheets of the former being connected by conducting wires, and all the sheets of the latter being similarly connected to represent the action of two single pairs. This form of battery has been denominated by Dr. Hare, "CALORIMOTOR," derived from two Latin words, denoting "heat mover."

Fig 78.

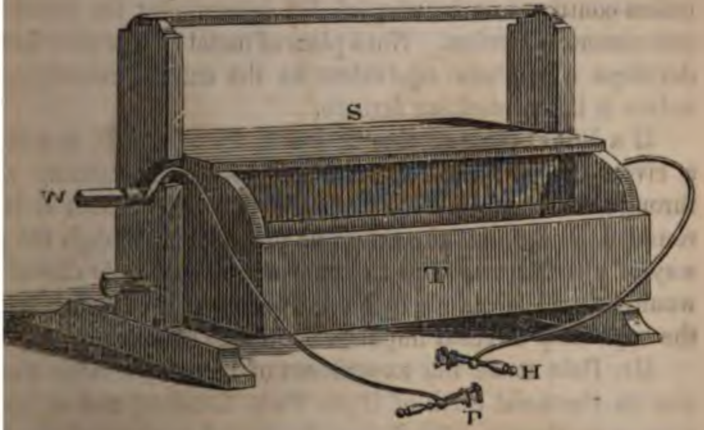


HARE'S CALORIMOTOR.—Dr. Hare devised a peculiar arrangement of the plates of a galvanic apparatus, in the year 1818, isting of twenty-one plates of copper, communicating by a of metal, and twenty plates of zinc similarly connected, the es of the one set being alternated between those of the other, constituting only an equivalent to one pair, with one asso-ed zinc surface, and one associated copper surface, with the id interposed every where between them. Dr. Hare remarks, ought to mention, that by means of a silver thimble, within ch a minute piece of zinc was supported and insulated, llaston made an elementary battery capable of igniting a ute platinum wire. In enlarging the size of the galvanic aratus, my course was diametrically opposite."

In the figure 78 is represented the plan of Dr. Hare's instru-nt of four zinc and six copper plates. On pressing down handle, G, the pulleys are caused to revolve, lifting by the l wound thereon the trough with the acid, whereby the plates immersed therein.

For the purpose of producing an intense action in burning or agrating metals, &c., Dr. Hare constructed a convenient appa-s upon an enlarged plan, with 200 pairs of plates, each 14 es by 7½ inches, with the copper and zinc plates soldered her in a wooden trough, T, on the "Cruikshank" plan, d lengthwise, edge to edge to another trough, so that when ides of one are vertical, those of the other must be horizon-

Fig. 79.



tal. These troughs being united by a bar, W, serving as a pivot when the bar is turned by a lever applied at W, the plates being placed in one of the troughs, and the acid in the other, by turning the trough containing the acid, it is caused to discharge its contents into the one containing the plates.

He made a very powerful battery by means of several sheets of zinc soldered together to form one continuous sheet, nearly fifty feet in length, with a similarly formed copper sheet of equal dimensions, wound together like a scroll, the two metals being kept separated by a rope of hair, wound intermediately between the sheets.

The calorific action of these galvanic batteries produced very surprising results in heating wires red hot, and in deflagrating metals, &c.

It is not necessary to place the zinc, iron, or other metals smelted from ores, within battery cells, in order to develope the electro-dynamic action consequent on their recoil to their natural polarized conditions; for in whatever situations they may be placed on the commencement of the change of their grouping from one polarized condition to another, the dynamic action ensues, although to human observation it may be undiscoverable, unless contrivances be adopted for determining the impulses in one common direction. Not a piece of metal rusts which does not develope a reaction equivalent to the action promulgated to reduce it in the smelting furnace.

If a bright plate of zinc be lowered into a well, or cast into a river, it begins to blacken and recoil, propagating action through the medium of the electric matter by which it is surrounded. But unless the action be propagated through the pathway of a conducting wire in some one determinate direction, it would be undiscoverable by human powers of perception, because the oppositely directed impulses neutralize each other.

Mr. Bain made the experiment of burying a large sheet of zinc in the moist earth of Hyde Park, London; and at another spot, more than a mile distant, he buried a sheet of copper of similar size. These two sheets he connected by a conducting wire, trained along the railings of the inclosure. With this simple apparatus he succeeded in producing the various phenomena usually obtainable from a regular galvanic battery. "Without troubling himself with the preparation of acids and voltaic troughs, he produced the excitation of regular electrical currents, of sufficient intensity to be transmitted to distant places along connecting wires."

It is stated by Mr. Tylee, a chemist of Bath, England, that a battery composed of thirty pairs of zinc and copper plates, which he buried in the moist earth of a garden, formed a *terrestrial battery* admirably adapted for electro-plating processes; but the time required for completing the process was longer than with the acid battery.

In his communication on this subject, addressed to Mr. Noad, he says, that he has never found the slightest variation in his battery (as indicated by the test of the deflection of the needle of a galvanometer) since he first arranged it.

In an experiment of plunging a plate of zinc in a dock of the city of Baltimore, sufficient action was developed to act upon the telegraphic apparatus located in the city of Washington.

As the chemical action of the pure water, in the preceding experiments with water-batteries is exceedingly slow when compared with the same water combined with acids, we have a clue to lead us to the philosophy of selecting acids, alkalies, and other similar substances for producing more effectively electrical excitation; for a small plate of zinc rapidly decomposed will serve to furnish as much electricity as a great plate slowly decomposed.

In the preceding descriptions of galvanic batteries, it will be recollected that the elementary atoms of oxygen, constituting about eight-ninths of the matter contained in common water, play a conspicuous part by their contact* and union with the zinc, in developing electro-mechanical forces. The same kind of elementary matter, oxygen, constitutes nearly one-fourth part of the matter of the atmosphere, which is in contact with all bodies. And, in addition, more or less water in the form of vapor, is always present in the air of the atmosphere. We are daily accustomed to see metals with polished surfaces become tarnished with rust, by the contact and union of oxygen therewith, such as has been described as taking place on the surface of zinc in the galvanic battery. As like causes produce like effects, we have therefore every reason to suppose that electrical excitations are constantly occurring in the rusting or decomposing of every piece of metal; and we shall presently show that the contact and union of the atoms of the oxygen of the air with various combustible elementary substances, constituting the process of the *burning of fuel*, serve to develope also electrical excitation.

It has been discovered by De Luc, that a very constant or durable galvanic battery may be formed, to be acted upon by the contact and union of the freely movable atoms of oxygen constituting the air of the atmosphere. This form of battery has been denominated

A Dry Galvanic Battery; or Pile of De Luc.

This kind of battery is constructed of sheets of paper, coated on one side with gold or silver leaf, and alternated with thin leaves of zinc. By means of a circular steel punch, about an inch in diameter, discs may be cut out of sheets of this paper foil, all of one exact size, adapted to be packed neatly together in a long glass tube. The atoms of the leaves of zinc very slowly become united with the atoms of oxygen of the air recoiling to their natural polarized conditions of groupings of an oxide, whereby a feeble propagation of electro-dynamic action is sustained during surprisingly long periods of time.

Mr. Singer constructed a Dry Pile of 20,000 series of discs of silver, zinc, and writing paper, which propagated an intense electro-dynamic action, like that produced by frictional electrical machines, causing a pair of pith balls of an electroscope to become divergent.

A pith ball suspended by a silk thread between two metallic knobs, one connected by a wire with the top cap of the pile, and the other with the lower cap of the pile, continued to vibrate unceasingly between the two knobs during several years.

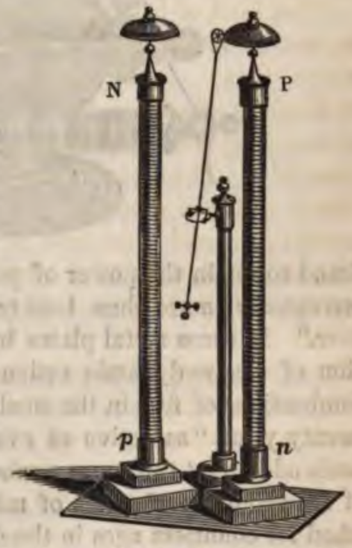
A thin glass jar containing fifty square inches of coated surface, charged by ten minutes contact with the column, was found by Mr. Singer to propagate sufficient electro-dynamic action to fuse one inch in length of platinum wire of the diameter of $\frac{1}{5000}$th part of an inch.

He states, that an efficient Pile may be made of one kind of metal only, as of zinc foil, if one side be made bright, and thus rendered more readily oxydizable than the opposite surface.

The black oxide of manganese contains an extraordinary excess of oxygen, capable of freely uniting with zinc and other metals. Zamboni improved De Luc's Pile by coating one side of the paper discs with this substance, mixed with sulphate of zinc, and the other side with tin foil. These piles are capable of developing sparks across a space of air of $\frac{1}{16}$th part of an inch, and also of producing chemical decompositions.

A pair of these Piles is exhibited in the wood cut, arranged side by side, with bells mounted on their summits, and a pendulum wire arranged to vibrate between them in order to produce a constant ringing of the bells. The two opposite poles are arranged against each other as denoted by the letters N P, *n p;* and the pendulum wire vibrates alternately from one to the other. This machine will keep up a constant ringing of the bells, producing sparks at every contact with the knob of the pendulum. After it had been constructed for more than ten years, upon being warmed, it would cause a strip of gold leaf to vibrate, as stated by an eminent experimenter.

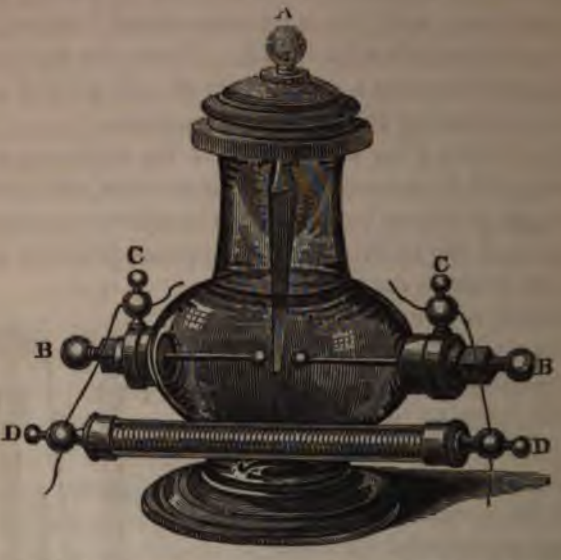
Fig 80.



To render this propagation of the electro-dynamic action more sensitively manifest, Dr. Hare contrived to arrange his single leaf electroscope in connection with a dry pile extended horizontally by the side of it, as shown in figure 81. The intensity of the electro-dynamic action in this case induces the effect of a constant attraction and adhesion of the gold leaf to the adjacent knob. This fact illustrates that galvanic action, as well as the action of frictional electricity, produces a polarization of the movable parts of the gold leaf and pith balls, and a resultant approximative, instead of repulsive, direction of electro-dynamic action.

The most instructive fact disclosed by the operation of the dry galvanic battery is the long continuance of its active dynamic condition. Mr. Sturgeon states, that "a Dry Pile has been found to retain the power of propagating electrical action, uninterruptedly, more than twenty years, and is still as active as ever." If these metal plates be capable of receiving a propagation of electro-dynamic action and polarization from the brief combustions of fuel in the smelting furnace, which will continue twenty years "as active as ever," it may be impressively comprehended, that the more perfect static condition of polarization of the grouping of atoms of mineral coal may remain undiminished for countless ages in the depths of the earth.

Fig. 81.



With the final change of the atoms of the zinc to their natural polarization of an oxide, or ore, this resultant dynamic action is terminated. But until this resolution of the counterbalanced Organic action and Inorganic reaction become completely effected by the final re-establishment of the resultant Inorganic reaction, there must be continuously propagated impulses of mechanical force to surrounding bodies through the medium of electric matter.

The counterbalanced Organic action, and Inorganic reaction, excited and continuously sustained by solar influence between the groupings of atoms constituting food, fuel, smelted metals, &c., become gradually resolved, in the Dry Pile, during a period of twenty years or more, into resultant dynamic impulses capable of moving continuously the pith balls, as above stated. The same counterbalanced action and reaction are continuously sustained between the atoms of matter in relative states of rest, holding them fastly united together in a consolidated form popularly denoted by the term "Cohesion." To this special subject we shall have occasion hereafter to refer.

The fact of this continuous propagation of mechanical impulses may be experimentally rendered manifest by means of the electro-polarization of the Dry Pile during periods of time which to brief human observation may appear like the "perpetual motion" of dreamy mechanics. Artificial freely movable bodies, resembling spiders in shape, with flexible threads representing extended legs, have been ingeniously arranged to imitate this busy insect, swinging to and fro incessantly, as if engaged in weaving his web, or moving his legs instinctively, on touching alternately each battery pole. The representation is very complete. Bunches of flowers have also been used to screen from sight the battery poles, and the effigy of the butterfly has been made to move continuously back and forth, as if fluttering between two bouquets.

Taking advantage of this long-sustained electro-motive power, an ingenious experimenter, Buzengeiger, attempted to render it available, for operating the pendulum of a clock. By means of this arrangement of a Dry Pile, the pendulum was alternately attracted and repelled. It was thus made to move the clock-work, instead of receiving its motion therefrom, as in ordinary clocks. In the year 1815, he thus succeeded in constructing the first *Electrical Clock* ever propelled by electro-motive power.

Mr. Bain has more recently employed electro-motive power derived from the recoil of large plates of zinc buried in the earth for the purpose of efficiently operating the wheel-work of town-clocks in England, as will be narrated in treating of the practical applications of electro-motive power.

As a continuous excitation of electricity produces a continuous action of impulses of mechanical force exhibited by the test of the long maintained swinging of the pendulum, so will the continuous action of mechanical impulses imparted to a pendulum, produce the continuous excitation of electricity. This fact may be verified in the following manner. Instead of the usual bob, let the insulated plate of an electrophorus (figure 54) be attached to the end of a clock pendulum, and let two resinous cakes, like that of the electrophorus, be so arranged as each to present its face to it as nearly as possible without actual contact. The manual operation of working the electrophorus may thus be imitated by the mechanism of the clock-work, the movement of the pendulum rod itself producing the necessary contacts and breakages of contact, by means of delicate springs, at the proper moment, at every successive vibration. The resinous cakes being once excited, will induce electrical excitation in the vibrating insulated plate, precisely as when it is held by the glass handle in the hand. The excited electricity is allowed to escape by the contact with the metallic spring, and the operation is repeated at each vibrating movement of the pendulum.

Thus the truth of the ever constant principle in mechanics of the equality of action and reaction, is sustained between electrical matter and all grosser matter; for it admits of demonstration, by the preceding experiments, that electrical matter will propagate impulses of mechanical force to move a clock pendulum; and *vice versa*, that impulses of mechanical force which move a clock pendulum, may be propagated in the modified form of electro-dynamic action. The reciprocal relationship between the movements of electric matter and mechanical movements of grosser matter becomes thus demonstrable.

A great variety of other arrangements of galvanic batteries have been constructed with different kinds of metals, some of them with iron plates instead of zinc, and others to be operated upon by alkaline solutions, instead of acids. To describe them all would far transcend our limits. The kinds of galvanic batteries in common use have been specified as serving, by their peculiar modes of construction and operation, to illustrate the principle of the continuous propagation of electro-dynamic action of the sun through the medium of electric matter, which constitutes the particular subject of our investigation in tracing out the sources of natural motive power.

EXCITATION OF ELECTRICITY BY HEAT, OR THERMO-ELECTRICITY.

PROPAGATION OF MECHANICAL ACTION THROUGH THE MEDIUM OF ELECTRIC MATTER IN THE MODIFIED FORM OF "HEAT."

THE term THERMO is derived from a Greek word signifying *Heat.* Although the branch of science designated by this name originated with the discoveries made so recently as the year 1822, by Professor Seebeck, yet it has already assumed an important rank among the acquisitions of human knowledge.

If it be admitted that electricity is the cause of the phenomenon of Heat, as has been previously detailed, it follows, as a necessary consequence, that wherever the phenomenon of Heat occurs, there must be a previous or simultaneous excitation of electricity, as an immediate precedent cause; and this conclusion is rendered the more probable from the fact, that all the causes of the excitation of the phenomenon of heat serve also reciprocally to render manifest the phenomenon of the excitation of electricity.

Dr. Turner reduces the sources of heat to six in number;—1, The Sun; 2, Combustion; 3, Electricity; 4, The bodies of animals during life; 5, Chemical Action; 6, Mechanical Action.

All these sources of heat are also sources of electrical excitation.

Although it remains to be determined whether electricity be the sole cause of heat, yet it is certain that electricity is one of the causes of heat, as above stated; and it is equally certain, that wherever the phenomenon of heat occurs, there is found to occur simultaneously electrical excitation, as we shall now proceed to show.

Although Thermo-electricity has become a regular branch of science within a few years, yet numerous facts of the excitation of electricity by heat appear to have been long popularly known.

In accounts of a species of silicious stone, denominated the Tourmalin, it was long ago recorded, that on suddenly plunging it into boiling water and then withdrawing it, light bodies were attracted, and exhibited flashes of light and electric sparks. The ready excitability of the tourmalin has served to amuse experimentalists in the same manner as the excitability of amber has served to interest and instruct successive generations of men.

The forces of attraction and repulsion developed by the tourmalin are distributed at its ends, similarly to the magnetic forces in the needle. The pieces of excited stones exhibit at the extremities two opposite poles, as characterized by positively and negatively electric action; whilst its middle part gives no sign of electric action. And when an excited tourmalin is broken into pieces, each fragment exhibits two opposite poles like the fragments of a broken magnet. These facts afford a remarkable illustration of the analogous action of the forces denominated electric and magnetic, which have been demonstrated in the preceding pages to be identical. This analogy is confirmed by the fact, that the polarity of the respective ends of a tourmalin excited by an *increase* of temperature becomes reversed, whilst the temperature is *decreasing*;—an effect which has been shown to be the unfailing result of a change of direction of electric currents.

The electrical excitation of the tourmalin is produced only whilst *changes of temperature* are taking place, as by suddenly heating or cooling the stone.

The impulses of mechanical force cease after a uniform temperature has been established. We are hence led to suppose that the phenomenon of this electrical action originates from the motion of electric matter in opposite directions.

It has been shown in treating of the movements of electric currents in similar and dissimilar directions, that precisely the same changes of polarity are produced in a freely movable conducting wire, through which a current of galvanic electricity is transmitted alternately in opposite directions.

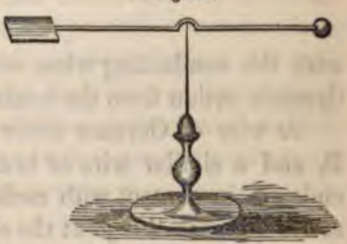
There are many gems and crystallized minerals, which render manifest the same electrical phenomenon as the tourmalin, on being similarly treated; and some diamonds even appear luminous for a time after being heated.

When pieces of calcareous spar, of mica, arragonite, quartz, and of several other kinds of stones, reduced to smooth parallel faces, are pressed between the fingers, the animal heat induces discoverable disturbances of the electric matter existing in connection with them. A piece of carbonate of lime has been found to exhibit sensible signs of electric excitation even at the end of ten days after it has been subjected to a momentary pressure from warm fingers.

Upon this principle of the development of electrical excitation is constructed the Electrical Needle of Haüy, represented in the annexed wood-cut.

It is balanced like a magnetic needle, having a little flake of carbonate of lime attached to one of its extremities, which is to be excited by pressure between the fingers. This instrument continues electrically excited for a considerable time, and is hence found to be one of the most simple and convenient tests for comparing the electrical condition of various kinds of bodies by contact therewith.

Fig. 82.



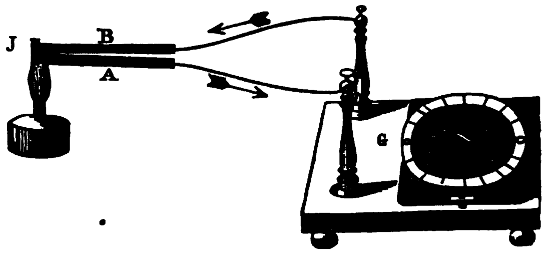
The inventor of this instrument ascribed the excitation to mechanical pressure, instead of to the heat of the fingers, which the preceding analogies point out to be the true cause.

Haüy demonstrated by his experiment that the polarity of the substances thus excitable is intimately connected with the constituent grouping of the atoms into crystalline arrangements, and also with the direction in which light is most freely propagated through them. The probability, if not the positive certainty, is demonstrated by this test, that the same cause which produces the phenomenon of heat, also produces the phenomenon of cohesion and solidity of atoms of crystal.

The discovery of electrical excitation in metallic bodies by sudden changes of temperature, was made by Dessaignes.

Many other similar facts, casually noticed from time to time, are recorded. They were not classified into scientific order until after the year 1822. In that year Professor Seebeck, of Berlin, discovered that electricity might be excited by holding the flame of a lamp against the conjoined ends of two pieces of wires, composed of different kinds of metal, as exhibited in the annexed figure, where the galvanometer, G, is shown in its connection with the conducting wires employed to propagate the electro-dynamic action from the heated ends of the wires.

Fig. 83.



A wire of German silver or of bismuth, is represented b B, and a similar wire of brass or of antimony, by A. The ends are in contact with each other, or slightly brazed togeth at J. Beneath this joint the exciting blaze of a lamp is applied the propagation of the electro-dynamic action being effected i the direction from the antimony to the bismuth, B, along the conducting wire, as indicated by the arrow, to the binding cup o the galvanometer. From thence it is propagated down the pos to the ends of the coils of wire arranged beneath the needle, an from thence by a returning circuit to the bismuth, at B.

The needle of the galvanometer is turned around or deflecte on its pivot in reversed directions where the connections of th two conducting wires with the two cups of the galvanometer ar reversed.

The discovery of Seebeck is of an exceedingly interestin character; for it evidently leads us directly to the palpable detection of the disturbance of the electricity naturally existing i a state of rest in connection with bodies by every change of thei temperature. And we are further led thereby to institute an inquiry, whether the converse of this fact be not true, viz., that every change in the electrical condition of bodies be not the exciting cause of changes of temperature, and of the consequent development of the impulses of mechanical force, which always become manifest on every change of temperature. This investigation is not, therefore, merely a curious subject of inquiry; but, on the contrary, a very important one, as solving the problem of the originating source of the most effective natural motive-power, which man has rendered available by means of the heat employed to excite the vapor of water in a steam-engine.

The philosophy of the employment of two different kinds of metals with contracted junctions in the formation of thermo-electric batteries, is simply to determine the propagation of electric impulses to one particular direction continuously, instead of allowing them to become diffused into numerous subordinate closed circuits in opposite directions. Without this arrangement they would oppose and counterbalance each other, and neutralize each other's action on the galvanoscope. This conclusion is established by the fact that the mere twisting of the middle of a wire, composed of one kind of metal, as of iron or platinum, or the joining together two pieces of wires of the same kind of metal, but of different sizes, determines the current to flow in the direction *from* the fine, through the more free channel of the coarse wire.

In the directions given by Mr. Davis for the practical use of thermo-electric pairs, he observes, that frequently, when the two pieces of metal "are merely made to touch each other, the current is greater than when they are brazed or soldered together."

If the connections be large, they allow the electrical reactions to recoil in closed circuits to the part of the metal whence it proceeded, without traversing the circuit of the wire extended to the galvanoscope; and consequently without being discoverable by this test of electrical excitation.

The analogy of this arrangement of the pairs of a thermo-electrical apparatus, to determine the propagation of electro-dynamic action *in one particular direction*, it will be here again noticed, is in very exact accordance with every other kind of electrical apparatus used for the purpose of developing the energy of electro-mechanical impulses. These electro-mechanical impulses are determined by the arrangement of the wires to act in coinciding directions, precisely as has been stated of the arrangement of the mechanism of the Current Changers of the magneto-electrical machine,—of the points on the frictional electric machine,—and of the copper plates of the galvanic battery.

Without these specific arrangements of dissimilar conducting bodies, it is manifest that the oppositely directed electro-mechanical actions and reactions must become equally diffused in every direction, and thus neutralize each other at the instant they are developed; so as to produce an electro-polarized condition of the atoms within the abbreviated closed circuits adjacent to the flame.

This action and reaction of the currents in these abbreviated closed circuits become more intense as they become more restricted to the parts of non-conducting bodies immediately excited. Although no electro-dynamic action becomes discoverable by the movement of the remote needle of the galvanometer when imperfect conducting bodies intervene, yet, the thermo-electric action of the abbreviated closed circuits becomes so much the more intense in the immediate vicinity of the heated part of the non-conducting body. Even the cohesion of the groupings of atoms finally yields to the overpowering thermo-electric action; and they become separated from each other to a gaseous state, or resolved into liquid states, as melted metals, &c.

These abbreviated electric circuits are doubtlessly induced, during the intense excitation of the forge-fire, in the end of every bar of iron, which the smith thrusts therein. During the recoil of the atoms of carbonaceous fuel, the polarity of the atoms of iron become finally counteracted. Vibratory movements ensue, which propagate an electro-dynamic action to the nerves of sentient beings recognizable as a *red heat.* The same reaction has been shown to occur when fine wires are subjected to intense electric excitation.

These analogies are sufficient to account for the conducting powers of various substances for propagating electro-dynamic action in the modified forms of "heat," and of "electricity." Silver is one of the best conductors of electricity, and it is also found to be the best conductor of heat. The facility with which thermo-electric currents find a more ready pathway through particles of silver allows of the extension of their closed circuits to produce vibrations of the particles of the conducting body at remoter distances from the excited point. Non-conducting substances, on the contrary, confine the circulation of thermo-electric currents to the most abbreviated closed circuits; and the electro-mechanical action becomes, consequently, more intense, in proportion as it becomes less diffused.

We have thus ample reason to conclude, that every piece of metal in which changes of temperature are taking place unequally in the different parts, serves as a true thermo-electrical apparatus.

Thermo-Electric Batteries.

After the successful experiment of the excitation of electricity by the heat of a lamp applied to the conjoined ends of two pieces of metal, it very soon became an object to ascertain the extent of the increased effect producible, by multiplying pieces of metals, in the same manner as has been narrated of the invention of the combination of the plates of the voltaic pile.

The metals selected experimentally for producing the most intense excitation of electricity by means of heat are, German silver* and silver, bismuth and antimony.

In the preceding figure, the current is determined in the direction from the bar of antimony, A, through the connecting wire and galvanometer to the bismuth, which constitutes the exterior circuit. The current passes from the bar of bismuth, in completing its closed circuits, back to the adjacent bar of antimony, through the heated conjoined ends. By considering the excitation as originating in the bar of bismuth, and as passing from thence to the bar of antimony, the former may be deemed positive to the latter, as the zinc immersed in the acid is deemed to be positive to the copper in the acid; but by considering the current to originate from the heated end of the bar of antimony, the opposite end must be regarded as the delivering or positive pole, and consequently positive to the receiving end of the bar of bismuth, B, thus reversing their relatively positive and negative conditions, as the copper is positive to the zinc on the parts out of the acid.

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*German silver is an alloy of 50 parts of copper, 30 parts of zinc, and 20 parts of nickel.

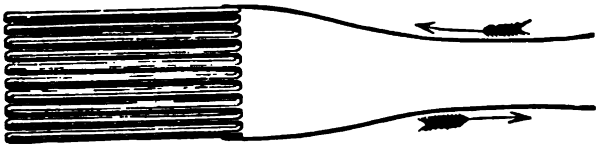
A current excited by heating the conjoined ends of bars of German silver and antimony to the same temperature, has been found to be comparatively more intense than that from bismuth and antimony, the divergency of the galvanometer needle produced by the latter being 75°, and by the former 85°, whilst their conjoined ends are alike plunged into hot oil of a fixed temperature.

By the test of very delicate galvanometers, every kind of substance capable of propagating electrical action, renders manifest a disturbance of the electricity naturally existing in connection therewith, by every disturbance or change of their temperature.

In experimenting with thermo-electric batteries formed of plates of bismuth and antimony, the bismuth being fusible at a low temperature, a very moderate heat must be applied. For this reason German silver and brass are preferred, as they admit of being safely excited by the contact of the red-hot iron, which will melt the bismuth.

To render the arrangement of the series of plates or wires of a thermo-electric battery more compact, they are laid side by side, as shown in the figure. They are insulated from each other by pasteboard, except at the ends, where the respective plates of bismuth and antimony, or of German silver and brass, are alternately soldered together, as in the arrangement of the series of plates of a voltaic pile.

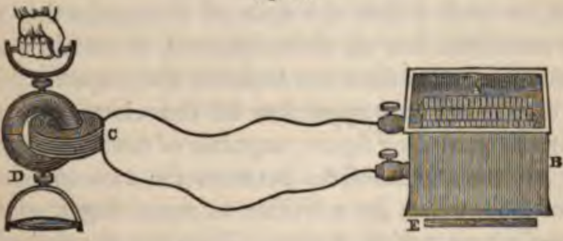
Fig. 84.



The figure represents a series of ten pairs. The heat of the palm of the hand held in contact with the soldered ends of this battery induces sufficient excitation to affect a galvanometer needle.

A more perfect thermo-electric battery is commonly constructed as exhibited in figure 85, consisting of 60 pairs of plates of bismuth and antimony, each $\frac{3}{4}$ of an inch broad, and $\frac{1}{4}$ of an inch thick. They are packed together in a case, B; but are insulated from one another, except at the soldered junctions of their ends, as above stated. The soldered ends of one series are arranged together on the under side of the case, where they may be heated by the radiation of the hot iron plate, E, the edge of which only is exhibited in the cut. The opposite series of the soldered ends are arranged together on the upper side of the case, as seen at A, which forms a reservoir for receiving a refrigerating mixture of snow or ice and table salt. The plates are insulated from each other, and from the case, by pouring fluid plaster therein; which also serves to render the consolidated mass impervious to the water resulting from the melting ice.

Fig. 85.



By thus combining two extremes of temperature at the opposite ends of the plates, there is produced a correspondingly extreme disturbance of the temperature of the plates, and development of electric forces, as tested by the two conjoined iron semicircles, D, environed by a coil of the conducting wire, C; whereby "a weight of forty or fifty pounds is required to separate them." Indeed, this thermo-electric battery is adequate to exhibiting various electro-magnetic phenomena which a galvanic battery is commonly used to exhibit; and also to give shocks and sparks.

ny, each 1½ inches wide and ⅓ of an inch thick, with thei tive conjoined ends exposed to the presence of a plate of at one extremity, and to ice at the other, Mr. Watkin sufficiently powerful thermo-electric currents to cause soft iron, inclosed within the coils of the conducting thereby converted into an electro-magnet, to sustain a 98 pounds suspended from the *keeper* of the magnet.

By employing the apparatus of the electro-dyna shown in the preceding figure, impulses of mechanical f even be *permanently established* between the two conjoi circles of iron, which are adequate to sustaining a con weight for a long period of time. Thus the blaze of a plied to the ends of the thermo-electric battery may cially caused to produce the result of a "cohesion" of joined halves of this iron ring, which strikingly resembl be not identical with, the COHESION established between pieces of iron by the heat of the forge in the process o this metal.

The process of *welding together pieces of metal even u mersed in cold water,* may be effected instantaneously b action, simply by their contact whilst they constitute opposite poles of a powerful galvanic battery. This ex affords an instructive lesson of the establishment of new conditions of groupings of atoms into consolidated mass no such agency as that of "heat" can be supposed to b

The ready propagation of mechanical action through the medium of electric matter to a distance, through conducting wires connected with heated bodies, may be illustrated, by descriptions of a plan published in the London and Edinburgh Philosophical Magazine for 1841, for ascertaining the heat of a furnace at a distance by means of a galvanometer.

Two plates, one of copper and one of iron, with the end of the one conjoined to that of the other, were inserted in the flue issuing from a furnace. The two other ends of the plates were connected by the circuit of a wire extended to a galvanometer stationed in a room one hundred and fifty feet distant. By means of this apparatus the writer relates that he could readily ascertain the state of intensity of the heat of his furnace by the mechanical action propagated through the extended conducting wire to deflect the needle from its usual north and south position.

This experiment illustrates, on a minute scale, the propagation of electro-dynamic impulses which may be similarly extended throughout the conducting matter of the earth's surface to vast distances; when the same exciting cause acts on this vast scale during the mid-day glare of the sun on the equator, and during eruptions of the craters of volcanoes. We have good reason to believe that similar deflections or perturbations of all the magnetic needles on the surface of this planet are thus simultaneously produced. Such occurrences of simultaneous perturbations are actually detected by the critical published notices of observations made at widely remote magnetic observatories.

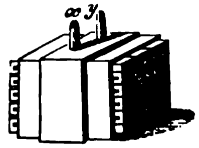
To test the propagation of mechanical impulses through the medium of electric matter between masses at sensible distances, the galvanoscope has been shown to be the most commonly employed instrument. But to test the same action between atoms at insensible distances, another instrument, the THERMOMETER, is universally employed.

Considering the phenemenon of heat to be produced by the vibrations of atoms of matter at insensible distances by means of electrical action, it is manifest that the greater the vibrations of the atoms, the more space they must occupy to allow them room for such vibrations. The Thermometer is constructed with reference to this principle. Some mercury, alcohol, gas, or other fluid, is confined within the restricted limits of a glass bulb with a transparent capillary tube attached thereto. Solid bodies, such as metallic wires, serve equally well for this purpose. In proportion as the thermo-electric excitation is increased, the vibrations of the atoms of the confined fluid become correspondingly increased, and more space is occupied by them to allow room for such vibrations.

This occupancy of more space by a mass of atoms is denominated EXPANSION, which is an inseparable phenomenon accompanying that of heat. This peculiar action upon atoms at insensible distances, is manifestly produced in the modified form of electro-polarizations; for on no other principle can we account for the expansion of water 1700 fold by an increase of excitation of only one degree of heat above 212° of Fahrenheit's scale.

The mechanical forces brought into action upon the needle of a galvanometer by slight disturbances of temperature, have been recently illustrated in an interesting manner by the experiments of Nobili and Melloni in France. The thermo-electric battery employed by them consisted of fifty small bars of bismuth and antimony, forming a bundle about one and a half inches long, and about one inch in diameter, inclosed in a band, as shown in the annexed figure. To facilitate the radiating and imbibing properties of the two extremities of the bundle of bars, the conjoined ends are all blackened. The extremities of the circuit are terminated at the two poles, x, y.

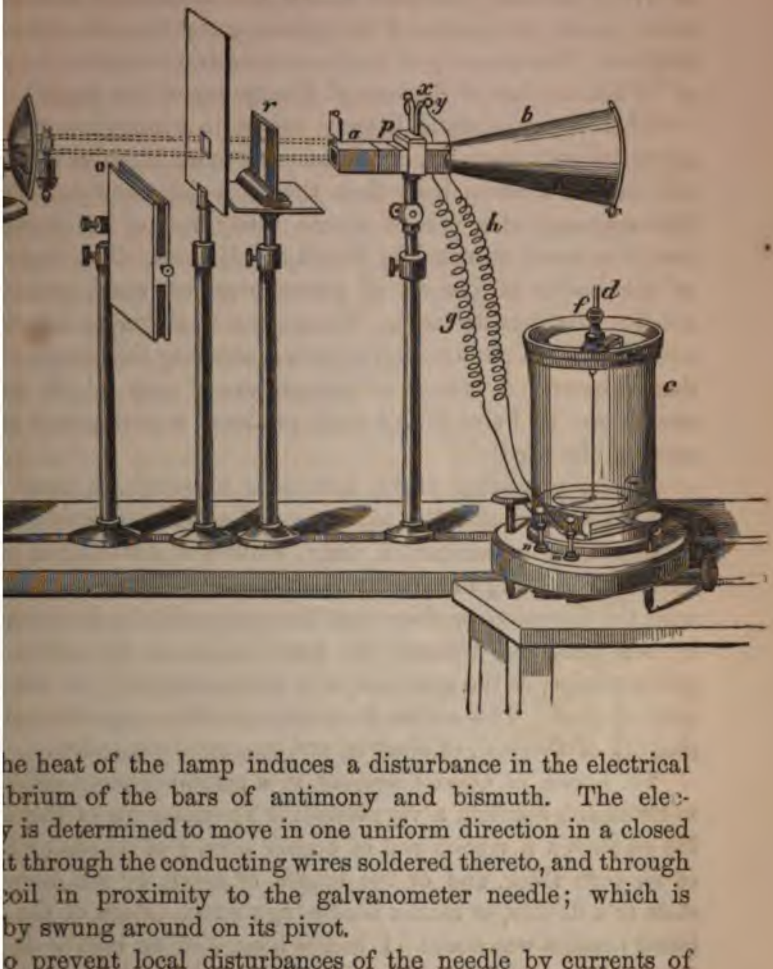
Fig. 86.



The bars of antimony and bismuth are insulated from each other by coatings of dry paper or silk throughout their lengths, and are soldered together alternately at their ends. The terminating bar of each series is separately connected with the ends of a wire forming the coil beneath the galvanometer, n, m, figure 87, in the same manner as the copper and zinc plates of a galvanic battery are connected by the wires, g and h, with the battery poles, x, y, of the preceding figure.

In the position of the instrument indicated in the figure, it is intended to denote at p, the blackened ends of the bars of the thermo-electric series, heated by a lamp, with a reflector. The dotted lines, representing the radiation of the heat through the ure of the screen, *r*; whilst the temperature of the other of the bars, P, remains the same as that of the surrounding

Fig. 87.



he heat of the lamp induces a disturbance in the electrical brium of the bars of antimony and bismuth. The ele- y is determined to move in one uniform direction in a closed t through the conducting wires soldered thereto, and through oil in proximity to the galvanometer needle; which is by swung around on its pivot.

o prevent local disturbances of the needle by currents of he galvanometer is inclosed under a bell-glass, and is sus- ed from *d* by a very flexible fibre of silk. To adjust the ment horizontally, it is mounted on three legs, composed e ends of screws, capable of being extended or retracted at pleasure. At *o* is a movable screen, designed to intercept the propagation of heat from the lamp, when an experiment is suspended.

The least radiation of heat from a lamp, or from the bodies of living animals, presented before the aperture of this instrument, causes the needle of the galvanometer to move around on its pivot. The intensity of the thermo-electric excitation is judged of by the number of degrees of divergency of the needle.

This thermo-electric battery, taken in connection with the appended galvanometer, consitutes a far more sensitive test of the approach of a warm body than the most delicate thermometer. The approach of a person within thirty feet of it, caused the needle to move, as stated by Nobili and Melloni. The slight heat of the bodies of insects, of phosphorescent wood, putrefying fish, &c., was thus detected. The apparatus, therefore, constitutes a most sensitive THERMOSCOPE, far transcending the powers of any thermometer. A change of temperature of only $\frac{1}{1200}$th part of one degree of Fahrenheit's scale produces a perceptible movement of the needle!

In the preceding pages, numerous experiments have been adduced to show that the movement of an excited conductor, or magnet, near an unexcited body, induces a disturbance of the electricity existing in connection therewith. These experiments with the thermoscope show that the approach of a body excited by heat produces precisely the same action on the needle of a galvanoscope, as the approach of a body electrically or magnetically excited. This serves to corroborate the supposition of the identity of thermal, of electric, and magnetic excitation.

Dr. Locke, of Ohio, describes, in a communication published in Silliman's Journal, a very sensitive Thermoscope of this kind. He employed a ribbon coil of copper wire, ¼ of an inch wide, [illegible] of an inch thick, and of the length of about 50 feet, arranged close to a double, or astatic needle (figure 29). Each of the co[illegible] bined needles was about 11 inches long, ¼ of an inch wide, a[illegible] $\frac{1}{40}$ of an inch thick. The size of this plate of bismuth a[illegible] copper soldered together and exposed to heat for inducing t[illegible] excitation of the thermo-electrical currents through the cop[illegible] fillet, arranged near this needle, was no larger than that of a [illegible]i ver shilling piece.

he mere warmth of the finger applied to this small pair of ,, propagated a sufficient electro-dynamic action to turn ıd the needle, weighing 1½ ounces, nearly 80°; but by ıs of the mechanism of current-changers, the connections and :sals being properly timed at every half turn of the needle, ıs made to swing entirely around, and to commence revolv- simply by the excitation induced by the heat of the finger. 3y placing this pair of plates, when blackened to imbibe the ʃs of heat," in the focus of a reflecting mirror, whilst the cir- is established between the two plates through this thermo- e, Dr. Locke states that, "the heat emitted by a non-lumi- ı ball at the distance of twelve feet, will also impel the needle ly 80°; and if the reversals and connections are properly timed ı current-changer, this needle may be made to revolve con- ally, so long as the heat of the distant ball continues to be ated through the air toward the pair of plates."

This is truly a most delicate test, not only of slight changes :mperature, as the best thermometer cannot compete with, also of the exertion of extraordinary impulses of motive er, propagated through the medium of electric matter in modified form of heat, across a space of air.

t has been found by Professor Henry, that if a thermo-elec- apparatus be applied at the point where the eye-glass is in- :d in the tube of a reflecting telescope, "the differences of ra- ons from small objects at the distance of several miles are :ted." So sensitively delicate is this Thermoscope thus ap- l, that it exhibits fluctuations of the needle whilst subjected ıe radiations concentrated by the telescope from different ng clouds, and "even from different parts of the clear ' This most remarkable statement illustrates an unexpected :onship between the use of the telescope for reflecting light, or propagating mechanical impulses through the medium of ric matter to move the mass of a magnetic needle on its

Vith this fact before us, who can doubt that the true philo- y of the use of the telescope is to concentrate mechanical n upon the material nerves of the eye, which constitutes a ıore exquisitely contrived electroscopic apparatus than that ;ructed by the art of man.

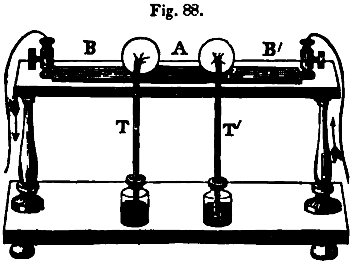
In the preceding details, the development of electro-dynamic action has been considered as taking place from the *additions* or *increase* of the exciting cause of heat, by the application of the blaze of a lamp, of a forge-fire, and of the sun, &c.

It admits of proof, that the sudden diminution of the cause of heat, or "cold," as artificially produced by means of refrigerating mixtures of snow and table salt, applied to chill the conjoined ends of the bars, will likewise induce the excitation of electricity. The currents will in this case flow in a reverse direction to their previous courses, when excited by an increase of temperature. Every disturbance of the temperature of bodies is accompanied by a disturbance of the electricity, naturally existing in connection therewith, and of their electro-polarization.

Mr. Watkins states, that brilliant sparks are obtainable, not only by pouring hot water over one end of the series of bars, whilst the other end remains at the temperature of the atmosphere, but that similar sparks are developed by simply applying ice to one end of the battery bars without recourse to the use of any kind of heated matter.

The following experiment may be introduced to exhibit the very interesting fact of a *decrease* of temperature producible *by reversing the direction* of the electro-polarization. The instrument which has been employed for this purpose is exhibited in the annexed figure, where two bars of bismuth, B B', are arranged at each end of an intermediate bar of antimony, A, to which they are soldered, leaving a little cavity at the conjoined ends to receive the bulbs of the two air-thermometers, T T'. A drop of water is placed in each cavity to facilitate the conduction of heat from the metals to the thermometers. On transmitting the current from a galvanic battery, in the direction denoted by the arrows, through the bismuth, B', to the bar of antimony, and thence to the other bar of bismuth, B, in the battery circuit, the thermometer T', arranged at the junction of B' with one end of A, will indicate a decrease of temperature, or *cold;* whilst the

Fig. 88.



thermometer T, at the junction of B, with the other end of A, will indicate an increase of temperature, or *heat*. And these phenomena of *cold* and *heat* may be reversed by reversing the direction of the galvanic current.

By actually applying a heated body to the junction of A with B′, or of a cold body to that between B and A, an electric current is excitable in the same direction as the battery current, the "current producing heat flowing in an opposite direction to the current which is produced by it."

The preceding experiment admits of being rendered still more interesting by placing a few drops of water in the cavity, at the junction between A B′, and by reducing the temperature of the water, artificially, nearly to the freezing point. When the current is now sent through these conjoined ends, the water becomes actually *frozen*, as affirmed by the experimenter, "during the abstraction of the heat therefrom by the electrical current."

The elevation of temperature in all these experiments, is always found to be comparatively greater than the depression or coldness produced. This result may be attributed to the rapidity with which the electro-dynamic action induces vibratory motion among the atoms of conducting bodies grouped at insensible distances; which vibratory movement we have supposed to constitute the phenomenon of heat.

The preceding experiments exhibit the most intimate relationship between the phenomena of changes of temperature ascribed to "heat," and those actually producible by the propagation of electro-dynamic action.

In the former case the phenomena are popularly ascribed to the action of heat or caloric, as a distinct "imponderable agent of nature;" in the latter case, the same excitation is similarly ascribed to the action of electricity, as another "imponderable agent of nature." The preceding experiments demonstrate conclusively that all the phenomena popularly ascribed to both of these "imponderable agents," are really producible at pleasure by means of the propagation of impulses of mechanical force through the medium of electric matter; and consequently they demonstrate the *identity of the cause of both of these phenomena*. Hence we cannot avoid the conclusion that the excitation of electricity by "heat," becomes resolvable into the excitation of electric matter at rest, in connection with portions of matter, by electricity in motion. In tracing out these analogies we finally become impressed with a clear conception of the true nature of "heat," as a modified propagation of mechanical action through the medium of electric matter.

The most powerful developments of thermo-electrical excitation have been shown to be producible when the opposite ends of the conjoined bars of metal have one of their extremities subjected to the disturbing cause of their electro-static condition propagated by the combustion of fuel, or by the more direct concentration of the electro-dynamic action of the sun's rays thereon, whilst the opposite ends are brought into contact with frigorific mixtures of snow and salt water, so as to produce the greatest possible contrasts of extreme differences of temperature.

The resemblance of this arrangement of the ends of a thermo-electric battery, with one portion subjected to the propagation of the electro-dynamic action of the sun, and with the other portion in contact with a frigorific mixture of ice and salt water, presents so striking a similitude to the natural condition of the mass of our earth, with its poles enveloped in perpetual glaciers, and icebergs floating in salt water, and with its equatorial parts subjected to the intense electro-dynamic action of the torrid rays of the sun, that the most superficial observer must notice it.

The contrasts of the temperatures of bodies producible by the contacts of different kinds of elementary atoms with each other, as when snow and salt water are commingled, are resolvable, in accordance with the preceding suggestions, into changes from one electro-polarized state to another; during which it has been repeatedly demonstrated in the course of our investigations of inorganic and organic formations, that electro-dynamic action ensues. A diminishing intensity of electro-dynamic action, like that shown at the junction of the bar of antimony and bismuth, A, B, in the preceding figure, produces the waning of this action, recognized as that of a *coldness;* whilst an increasing intensity of polarized action and reaction between the atoms at insensible distances produces the augmentation of their vibratory movements, recognized as that of *increased heat.*

The following table shows the change of intensity in the propagation of electro-dynamic action in the modified form of changes of temperature, producible by the contact of groupings of atoms of the crystals of water in the form of ice or snow, with a few kinds of groupings of other elementary substances.

Frigorific Mixtures in Relative Proportionate Parts.

Mixtures of			Fah't Scale
Snow and pounded ice . .	12	Become reduced from any temperature to . . .	0°
Chloride of sodium (table salt)	1	If violently stirred together	— 25°
Snow	1	From + 32° to . .	— 50°
Crystallized muriate of lime .	3		
Snow	8	From — 50 to. . .	— 90°
Diluted sulphuric acid . .	10		
Solid crystals of carbonic acid .	—	In passing from a solid to an aeriform state receive the reaction from adjacent bodies until their temperature becomes reduced to . . .	— 148°
		being the extreme of cold producible artificially.	

The novelty of the preceding facts of the excitation of electricity by heat, may serve to surprise the reader; particularly when he has been taught to believe in the existence of Heat and Electricity as two distinct "imponderable agents" of nature. The discovery of Seebeck might be regarded as the employment of one agent of nature, as it were, to awaken and excite another.

But this surprise vanishes when a comprehensive view is taken of the systematic propagation of impulses through the medium of electric matter, which have been detailed in the preceding pages. It is only necessary to reflect that every gleam of lightning which we behold darting forth from thunder clouds in a summer sky is excited directly by the disturbing action of the sun, propagated to the surface of lakes and oceans; and that it has been demonstrated that the phenomena of heat, light, electricity, animal motive-power, and steam-power, represent so many differently modified mechanical effects produced by continuously repeated impulses, originating from the electro-dynamic action of the sun, and propagated through the medium of electric matter.

It has hitherto been successfully urged as an unanswerable argument in favor of the theory of the existence of heat as a distinct agent of nature, that there is a transference of its agency from body to body, traceable from its entrance to its exit therefrom, never lost, and never annihilated. These facts have established an idea of the "materiality of heat," and of its substantial existence as an imponderable agent. But when this argument is examined by the steady light of mechanical philosophy, it will be found to present a most beautiful view of the unvarying truthfulness of the universal system of propagation of mechanical action through the medium of electric matter.

That heat is continuously traceable from the time when it enters a body, until it comes out therefrom, and is indestructible, the whole train of facts detailed in the preceding pages have been specially adduced to prove and maintain. The perfectly mobile medium of electric matter, when it receives an impulse, must continue to propagate it for ever, or until counterbalanced by an oppositely-directed impulse; for a mechanical impulse, when once originated, like atoms of matter when once created, cannot be annihilated. The science of mechanics, indeed, has been classified into the two grand subdivisions of *Statics* and *Dynamics*, for no other purpose than to sustain and carry out this fundamental law.

Organic and inorganic formations have been adverted to, with a special design of illustrating this fact. It has been shown that even electro-dynamic impulses propagated through the medium of electric matter from an antediluvian sun, in the modified form of heat and light, have not been lost or annihilated. On the contrary, these impulses have been reduced to constrained counterbalanced static conditions in the polarizations of atoms grouped into organic formations of mineral coal; whereby impulses of electro-mechanical action propagated to terrestrial matter before the flood, have been reduced, through the medium of the perfect mobility of electric matter, to counterbalanced static conditions, capable of reacting, or recoiling, at the expiration of thousands of years afterward, against the yielding piston of a steam-engine.

When it is also recollected that an impulse of mechanical force propagated through the medium of electric matter may be artificially modified to produce the identical phenomena popularly ascribed to heat, light, electricity, steam-power, animal motive-power, magnetism, &c., there appears to be no escape from the conviction that the excitation of electricity by heat is resolvable simply into this continuous and indestructible propagation of mechanical impulses through the medium of electric matter.

The phenomenon of "latent heat," in accordance with Dr. Black's theory, admits also of an admirably simple illustration by the application of the principle of the continuous propagation of mechanical action, between groupings of atoms, through the medium of electric matter, through successive static and dynamic conditions of their polarizations.

The constancy of the united sum of the "latent" and "sensible heat" of steam, and of other groupings of atoms, demonstrate that, in proportion as the vibrations of the exterior molecules increase, those of the interior molecules diminish; and hence may be theoretically inferred, what is always found to be practically verified, that the counterbalanced molecular forces of the atoms become resolved into dynamic action of the mass; and fluidity or fusion begins, where the molecular polarity ends.

The preceding inquiry into the nature or cause of "heat," is essential in tracing out the originating cause of excitation of electricity during the development of the phenomenon popularly denoted by the term "Thermo-electricity." The excitaton of the phenomena of heat, has been repeatedly referred to as an effect produced by the propagation of electro-dynamic action through fine wires; and to admit that an effect produced can be a cause, or that two causes can reciprocally reproduce each other, appears to be so unphilosophical an idea as to be unworthy of being longer maintained in popular belief.

EXCITATION OF ELECTRICITY BY LIGHT, OR PHOTO-ELECTRICITY.

PROPAGATION OF MECHANICAL ACTION THROUGH THE MEDIUM OF ELECTRIC MATTER IN THE MODIFIED FORM OF LIGHT.

THERE is as sufficient a reason for ascribing a power of exciting electricity to Light, as there is for ascribing the same power to Heat. The propagation of mechanical action through the medium of electric matter in the modified form both of Heat and Light, have been shown to be identical, the principal distinction being the contingent fact, that a different class of material nerves of sentient intelligent beings are necessarily employed as electroscopic standard tests to determine the intensity of their action, as has been previously narrated in detail. Although there may be a different line of the propagation of mechanical action in the modified form of Light, from that which takes place in the propagation of the same action in the modified form of Heat, as occurs in the difference of refrangibility of their respective impulses, yet this very difference may be assumed to represent a corresponding difference of the intensity of the impulses propagated through a refracting transparent medium. Light and Heat are both simultaneously propagated by the solar action on terrestrial matter; and a resultant electrical excitation is as unfailingly developed simultaneously with the occurrence of the former as of the latter.

The experimental use of the telescope to propagate mechanical action to move the needle of a galvanoscope, as has just been narrated of Professor Henry's experiment, is a conclusive proof that the functions of this instrument, which is eminently distinguished above all others for its power of refracting and reflecting Light, are positively based on the propagation of mechanical action to the electroscopic material nerves of sentient intelligent beings.

That the propagation of mechanical action through the medium of electric matter constitutes "light," is also demonstrated by the recent and truly surprising discovery of the Daguerreotype process; in which the differences of shades and lights, thrown on a sensitively prepared electroscopic plate of silver, really become resolved into so many exquisitely defined differences of intensity of electro-mechanical action; whereby the atoms of mercury, caused to rise up in steaming vapor against the surface of the plate by the polarizing excitation of the heat of a lamp, become most strongly urged toward the parts which have been most strongly affected by the light, and feebly, or not at all, where no rays of light have been incident. The accumulation of the silvery white globules of mercury on the dark lustrous surface of the plate represents the bright lights of the pictured image formed by the lenses of the object-glass in the camera obscura. The absence of the silvery white globules of mercury constitutes the dark shades of the picture.

Thus, one of the most beautiful and interesting of all recent modern discoveries, that of producing pictures by the influence of light, is adducible as one of the most complete and undeniable tests that this hitherto-supposed "imponderable agent" really becomes resolvable simply into a modified propagation of mechanical action through the medium of electric matter; and the perception of *shades of colors* may in like manner be traceable to differences of intensity of this mechanical action on the electroscopic nerves of the eye, as will be shown in treating of Light.

The philosophy of the Daguerreotype process will presently be considered in distinct chapters appropriated to analyzing the phenomena of Heat and Light.

The slight mechanical action of the touch of a feather is sufficient to determine a change of polarization of the groupings of atoms into certain compounds denominated fulminating powders, and a slight mechanical action of friction is familiarly applied to ignite the materials of friction matches. The mechanical action propagated by an electric spark will also polarize the commingled atoms of hydrogen and oxygen gases, causing them instantaneously to become reduced to liquid water. The following experiment will demonstrate that precisely similar results of the propagation of mechanical action, are producible by a gleam of sunshine. A glass flask is surrounded by a wire gauze to protect the eyes of the experimenter from the fragments of glass, which are explosively scattered by the ignition of equal measures of hydrogen and chlorine gases commingled therein. The mechanical action propagated in the modified form of light will kindle these commingled gases, as an electric spark kindles the commingled hydrogen and oxygen gases. Immediately after commingling the two gases, the light from a mirror placed in a situation to reflect the solar rays, is directed upon the flask, when an explosion ensues.

The gases, after their explosive reaction, become united by a new order of electro-polarization with the atoms of water in the bottom of the vessel, constituting the powerful muriatic acid. This acid carries with it a similar remarkable power of inducing electro-polarizations, causing dark-colored vegetable bodies to reflect red and other bright rays of light, to act upon the sensitive electroscopic nerves of the eyes of sentient beings.

The preceding facts will be sufficient to prepare the way for subsequently resuming these investigations more fully, and to demonstrate that all our knowledge of light is based on the propagation of mechanical action through the medium of electric matter.

We shall now proceed to show that all the preceding modes of producing electric excitation, are resolvable, simply, into the—

EXCITATION OF ELECTRICITY AT REST BY MEANS OF ELECTRICITY IN MOTION, DENOMINATED INDUCTIVE EXCITATION.

In treating of the excitation of electricity by electrical machines, it has been shown that the movement of one portion of matter near another at sensible distances, each carrying with it its respective electrical atmosphere, reciprocally disturbs the state of rest of these atmospheres, and produces the phenomena of electrical excitation. The excitation in these cases is manifestly produced by the movement of electric matter in connection with the movements of grosser solid and fluid matter. The action and reaction take place between the electric matter circulating among the atoms of grosser matter, as has been premised, producing their respective polarizations.

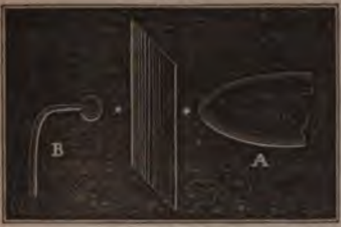
The disturbances of their electrostatic conditions are due, therefore, to the action of electric matter on electric matter. Whether the electricity be put in motion together with the moved bodies, or independently of their motion, it serves equally to induce movements of electric matter in connection with the approximated bodies near which it may move.

This mode of exciting electricity by means of electricity, has received the name of INDUCTIVE EXCITATION, as before stated; and constitutes a general law of the propagation of impulses through the medium of electric matter. Considering all portions of matter of sufficient magnitude to be discoverable by human powers of perceptions and to be constituted of atoms grouped together by the continuous propagation of the electro-dynamic action of the sun, as has been previously detailed in describing *Polarizations* of Inorganic and Organic formations, it follows as a consequence, that the properties of conduction and non-conduction of electric action, which various bodies exhibit, must be due to their specific states of electro-polarization.

This fact may be satisfactorily demonstrated by the following experiment with the substance of glass, which is commonly selected by experimenters as one of the most perfect "non-conconductors" of electricity.

Interpose a plate of glass between the excited conductor of

Fig. 90.



an electrical machine, A, and the knob of a discharging rod, B, as shown in the figure. The sparks from A will appear to pass through the glass to the knob B. They become simultaneously visible on both sides of the plate, as shown in the figure. The electro-dynamic action is propagated quite as intensely through the non-conducting glass, as through a plate of conducting metal. If the knuckle be substituted in place of the knob, B, every spark from A will affect the material nerves of feeling as intensely as if no "non-conducting" glass intervened.

After continuing this experiment for a short time, it will be discovered that the sparks from the conductor become gradually less intense, until finally the electro-dynamic action ceases to be propagated through the glass; after which, the plate may be considered truly a "*non*-conductor." It is now reduced to a *polarized* state.

The preceding experiment demonstrates that glass, to a certain extent, is a very ready conductor or propagator of electro-dynamic action. The property of "non-conduction" cannot, therefore, be inherent in the material atoms of the glass, but is manifestly contingent on a certain constrained condition denominated Polarization, to which it becomes reduced. This experiment also demonstrates that the conducting property of glass is the result of an electro-polarization of the two opposite surfaces, and of the intermediate atoms between these surfaces. Unless the particles of the glass become polarized, they cannot serve to propagate electro-dynamic action. The perfectly mobile electric matter occupying the surface of the sheet next the excited conductor, A, cannot receive an impulse, unless it be enabled to propagate it. If there be an arrangement of lines of particles which are reduced to such a constrained electro-static condition of groupings as to remain unaffected by the propagation of electro-dynamic action, their previous polarization precludes the further extension of mechanical action through the medium of electric matter. This fact appears to determine the distinction between conducting and non-conducting bodies.

preceding experiment, the thinner the glass, the more
ecomes the polarization of the atoms intervening be-
two opposite surfaces; until the previous polarization
atoms, constituting the phenomenon of cohesion, is
erpowered. By attempting to carry out this principle
ıg a very intense electro-dynamic action from the dis-
electrical or Leyden jars, by using extremely thin
ave found that the intensity of the polarization of the
ıss of the glass overpowered the polarization of the
l atoms of the mass; whereby they were caused to
the sides being perforated by a spontaneous discharge,
ır thus rendered unfit for further use.
ınection with the subject of Inductive Polarization, the
ion of the general principles or laws which govern
ılarization will afford instructive information in this
science.

PRINCIPLES OF ELECTRO-POLARIZATION.

ıolarization of a plate of glass has been described in the
paragraphs. As a substitute for the knob, B, let the
he hand be held against the surface of the glass plate.
ark from the conductor A will be felt as a shock propa-
the hand at the spot where the spark is incident. The
echanical impulses are propagated through the glass by
ization of the intervening atoms.
ɔportion as the polarization of the mass of glass becomes
ɔnse, it appears that the molecular polarization of the
nt atoms becomes less intense; until the former over-
ıe latter. This fact is verified by the breaking of the
ıe glass by a spontaneous discharge, as stated in the ex-
with thin glass to which allusion has just been made.
ıilar relative polarization of the mass and of the compo-
ms, occurs in the phenomenon of "latent heat," and
heat." The former represents molecular action, and the
action external to the mass. The one does not act on

the thermometer, and the other does. It has been stated by experimenters with the vapor of water, that the *latent* heat diminishes as the *sensible* heat increases; so that the sum of both remains always the same, or a constant quantity.

The analogy appears to hold good when applied to the latent molecular action, or rather electro-polarization, of the atoms, and to the palpable electro-polarization of the mass. There is reason, therefore, for believing that the phenomenon of the electric excitation of the mass of a body may simply represent the disturbance of the natural polarization of the component atoms of the body.

By applying this principle, it may be assumed that the material of the glass, constituting a Leyden jar, may perform the functions of receiving a charge of electricity and of discharging it, without any transference of the constant quantity of electric matter resting in connection therewith. For if the discharge of a jar be only the propagation of mechanical action through the medium of electric matter, the quantity of electric matter employed is not to be taken into account as absolutely essential.

A precisely similar reciprocal change from the polarization of the mass to that of the molecules, is discoverable in experimenting with a bar-magnet. By pulverizing a tempered steel magnet, every individual fragment, however minute, developes the distinct polarization of a perfect magnet; when reunited, their individual or molecular polarity, becomes latent, being resolved into a resultant force at the extreme ends of the mass, or at the *poles*, producing the phenomenon of polarization.

If, again, the two extreme ends or poles of a piece of steel be bended around and united together to form a complete ring, an entire circle or circuit of molecular polarizations of the atoms is thus established. It is found impossible by the experimenter to detect polarity in the circular mass of this ring, however strongly it may be magnetized. A steel ring exhibits no magnetic polarity.

This result is sufficiently manifest, if theoretically considered; for there can be no polarity, where there are no poles, or ends to be polarized.

The excitation of a steel magnet admits of being discharged like that of a Leyden jar. This result is very commonly effected by interposing a connection of readily polarizable atoms, denominated the *armature*, between the two ends or poles of a bar magnet, as a similar connection is established between the two surfaces of a jar. Just in proportion as the armature or cross-piece of iron is slided along toward the two poles of an U magnet, its magnetic forces are found to diminish in intensity, until they disappear almost entirely, when the connecting bar is adjusted against the extremities of the two poles. By resorting to this artificial expedient, the steel magnet, the Leyden jar, and galvanic battery, become alike reduced to circles of forces, briefly denoted by the term, *circuit*.

These illustrations demonstrate that the atomic polarization becomes resolved into that of the mass; and that the polarization of the mass becomes resolvable again into a complete polarization of the atoms by establishing a connecting *circuit* as above described.

To verify the latter fact, it is only necessary to regard the perfect development of the propagation of electro-dynamic action between atoms, constituting the circuit of a galvanic battery whilst employed in accomplishing the process of electro-plating metals. The atoms of a bar of solid silver are separated from one portion or pole of the circuit, and by the artificial substitution of yielding fluid atoms constituting an adjacent portion of the polarized circuit, they are transported across it, and the same system of polarized action between the atoms is re-established at another portion of the circuit, constituting the molecular force, denominated "cohesion."

The points of the conducting wires terminated in the liquid solution used for electro-plating metals, do not therefore constitute perfect poles, like that of the end of a bar-magnet; but rather represent partially disconnected poles, like those of two magnets with a contracted space of air intervening between them. The propagation of the electro-polar action may be impeded, but it is not suspended thereby; and whilst the atoms are separated from each other at one pole, they are united together at the other pole, with the concomitant circumstance of the re-establishment of a molecular action identical with that popularly recognized as "cohesion."

When the electro-polarized circuit is established among the atoms of solid bodies, as in the conjoined segments of the ring of iron, exhibited at page 248, fig. 44, the sensible magnetic forces become resolved into latent molecular forces. The electro-dynamic action developed at one pole being in a similar direction to that developed at the other, when the ends are bended around to form an entire ring, the propagation of this action in similar directions about portions of matter always induces the phenomena, of attraction and a static condition of them, as has been repeatedly stated. It follows that the establishment of *circuits* throughout a series of atoms is competent to producing and sustaining the groupings of atoms into masses of sufficient magnitude to become discoverable by human powers of perception.

As a polarized circuit cannot be composed of a less number than four atoms conjoined to constitute a rectangular arrangement, this circumstance appears to furnish additional proof that all knowledge of the existence, as well as of the properties of the sixty different kinds of elementary substances, is limited to that of the electro-polarization of the atoms. The *Properties* of matter represent these relative static conditions of the groupings of atoms, and the resultant action developed on every change from one polarized static condition to another.

These analogies render the supposition probable, that the phenomenon of the discharge of the Leyden jar may be considered simply as a change from the constrained polarization of a mass of atoms to the natural polarization of the molecules.

In treating of the phenomena of attraction and repulsion produced between the pith balls of electroscopes and other polarized bodies serving to propagate electro-dynamic action in similar and dissimilar directions, it has been premised at page 256, that these phenomena are traceable to similar and dissimilar polarizations.

In closing this subject it may be here noticed that there cannot be a natural static condition of polarization of freely movable portions of matter, resembling that of the Astatic Needle, (represented by the wood-cut at page 232,) because this peculiar arrangement is strictly an artificial one. If the two combined needles were free to move, like the floating rings of De La Rive, would directly recede from one another.

ombined artificial arrangement of these two needles to-
owever, serves admirably to illustrate the fact that when
intensity of polarized action between atoms or masses
iere may be a perfect neutralization of their combined
influence on approximated bodies. By artificially con-
em together, the polarized action between the two masses
equivalent to a molecular action between the parts of a
ass.

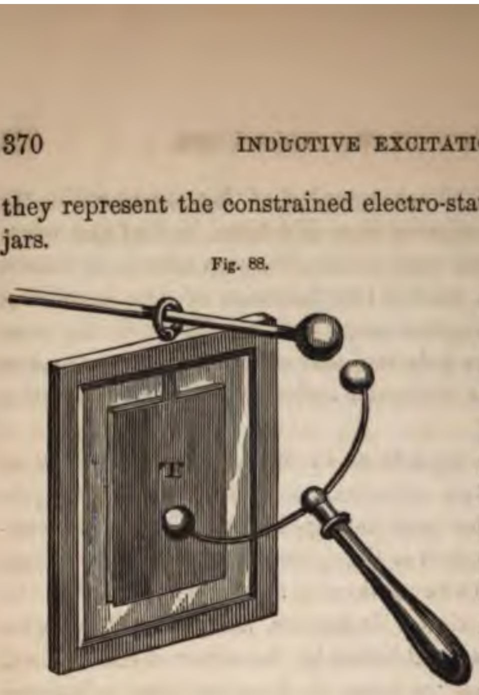
two natural polarizations of bodies bring portions of
ogether into two arrangements, one with their equa-
rts, and the other with their polar or axial parts in con-
ll further movement is thus precluded, by the law of me-
stablishing that two portions of matter cannot occupy the
ce at the same time. It follows, as a necessary conclu-
the principles established by the electro-dynamic key,
, that the general tendency of all natural electro-dynamic
to urge portions of matter reciprocally toward each
entres, thus constituting an universal law equivalent to
OHESION between atoms at insensible distances, and to
RAVITATION between masses at sensible distances.

iis subject we shall again have occasion to recur when
iomena of cohesion and gravitation are reviewed. We
resume the investigation of the phenomena exhibited
eyden jar.

mere contact of the palm of *one* hand with either surface
ass, as described in the experiment above recapitulated,
restore the equilibrium of the disturbed electrical exci-
It is necessary to apply the palm of the other hand si-
ously to the opposite surface of the glass plate. By this
a continuous line of readily polarizable particles of the
matter of the muscles and nerves of the arms and chest
posed, to form a connection between the opposite sur-
the polarized plate. An instantaneous change of polar-
f the plate is now found to take place, from its constrained
dition, in which the intensity of the molecular polariza-
eakened, to a natural static condition, in which the in-
f the molecular polarization is re-established.

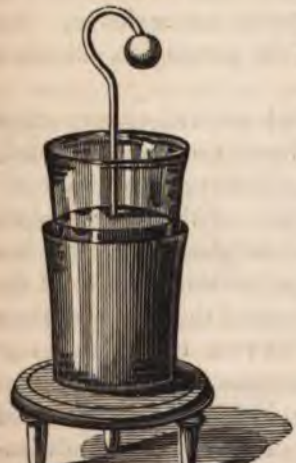
n the sides of a plate of glass have been electro-polarized, they represent the constrained electro-static condition of Leyden jars.

Fig. 88.



The sheets of tinfoil, or metallic leaves, are affixed to the internal and external surfaces of the jars to propagate the electro-dynamic action instantaneously to all parts, by the facility of the electro-polarization of the atoms of the metals. This arrangement is exhibited more distinctly by the coated glass plate, T. If the knob of a discharging rod, formed like a pair of tongues inserted in a glass handle, be brought into contact with one side, at T, and then into contact with the other side, through the connecting knob projecting from that side, both sides become restored instantaneously to their natural electro-static, or polarized condition.

Fig. 89.



That the metallic coatings serve no other purpose than to facilitate the propagation of electro-dynamic impulses, is demonstrable by the follow ing experiment.

Let a metallic case be fitted to the exterior surface of a glass tumbler; and another similar case to the interior surface; both of which coatings are to be made of stiff metal, so as to be movable at pleasure. The tumbler being charged from an electrical machine in the usual way, the interior movable coating is first lifted up out of the tumbler by means of a glass rod passed under the hook affixed thereto; and then the tumbler is to be grasped by the upper edge or rim, and lifted out of the lower case, whereby the three pieces are all separated.

After this operation the metallic coatings may be handled at pleasure, leaving the tumbler undisturbed; and when the coatings are afterwards carefully restored to their proper places in connection with the tumbler, the opposite electro-polarizations may be caused to neutralize each other's action, by means of these plates, by interposing a line of polarizable particles of some conducting body.

It is amusing at the present day, when the powers of the Leyden jar are familiarly known, to review the history of the early experiments which led to its discovery.

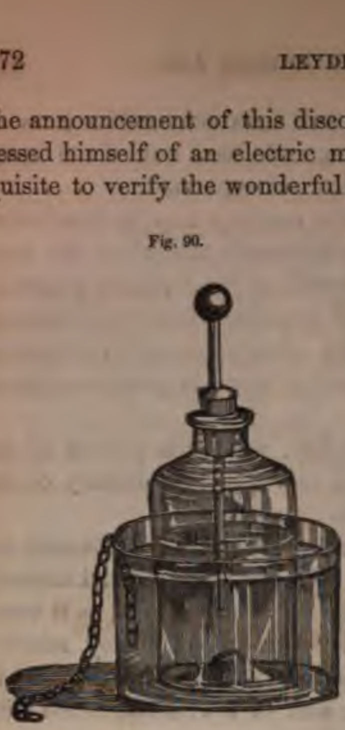
About the year 1746, Muschenbroeck, Kleist, and Cuneus, entertained the idea, that electricity might be collected and inclosed in a non-conducting vessel of glass, so as to be kept, as it were, bottled up, ready for use whenever required. They selected water as a suitable fluid to be combined with the electric fluid in a bottle, and inserted therein the end of a wire connected with an electrical machine.

After operating the machine for a time, one of the party, who held the bottle in one hand, attempted to withdraw the wire with the other. He received a shock, which, although feeble when compared with those which have been unflinchingly taken by subsequent experimenters, was so sudden and unexpected, whilst the nature of it was so entirely unknown, that it was described at the time with extraordinary hyperbolical exaggerations.

Muschenbroeck stated, in a letter to Réaumer, that "he felt himself struck in his arms, shoulders, and breast, so that he lost his breath; and it was two days before he recovered from the effect of the blow, and the terror;" concluding, "he would not take a second shock for the kingdom of France." Winkler affirmed, that in making the same experiment, "he suffered great convulsions through his body; that it put his blood into great agitation; and fearing an ardent fever, he was obliged to have recourse to cooling medicines." His wife appears to have been quite oppositely affected; for after having taken the shock, she was rendered so weak by it that "she could hardly walk."

Great, indeed, was the excitement universally produced by the announcement of this discovery. Every scientific man possessed himself of an electric machine and of the apparatus requisite to verify the wonderful experiment.

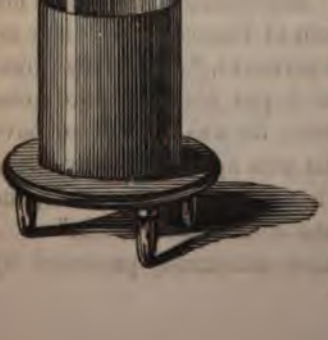
Fig. 90.



In the original mode of arranging the bottle, it was nearly filled with water, and corked with a wire inserted through the cork and then placed in a vessel of water as shown in the wood-cut. This mode of arrangement constituted the original "Leyden jar,"—so named from the city where the experiment was first made.

Subsequent experimenters employed metallic coatings of brass filings; and finally others employed gold and silver leaf and tinfoil. In th first experiment the palm of the hand grasping the bottle serv partially as the conducting coatin and the water in the external vess was afterwards used for the sam purpose. By these improvemen the Leyden jar was brought t its present form, as exhibited i the cut. A single jar being foun capable of producing a limited e fect, the number was afterward multiplied, to increase correspon ingly the electric power; whereb animals were killed, as by light ning, by the violence of their si multaneous discharge. These com bined series of jars were terme "batteries," from the fancied re semblance of their discharge to th combined action of a battery o cannon.

Fig. 91.

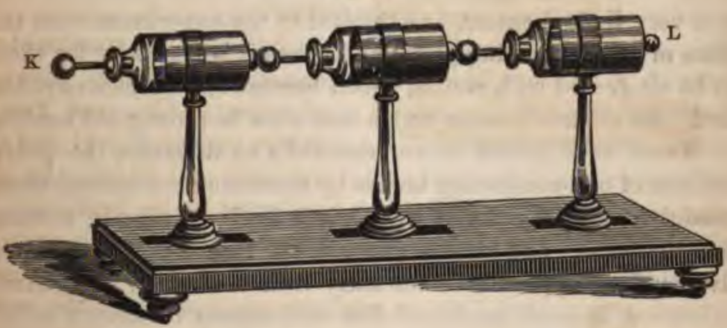


MECHANICAL IMPULSES PROPAGATED THROUGH SERIES OF ATOMS AND MASSES BY MEANS OF THEIR ELECTRO-POLARIZATIONS, CONSTITUTING THE PHENOMENON OF INDUCTION.

The propagation of mechanical impulses through far extended series of non-conducting, as well as conducting bodies, admits of being effected by successive polarizations, thus demonstrating the probability, if not the certainty, that the phenomenon of CONDUCTION is ascribable to electric-polarization.

This fact admits of verification through a series of non-conducting glass jars, coated with sheets of tinfoil or other metal on their external and internal surfaces, arranged in an extended line, as shown in the figure. On the passage of an electric spark from an excited body to the knob K, the electro-dynamic action is propagated throughout the coating of tinfoil lining the interior of the first jar, and from thence through the sides of the glass to the metal coating of the exterior surface and to the knob of the next coated glass jar; and from thence simultaneously through a series of similar non-conducting surfaces of glass to a distance, L, where a spark may be felt in the knuckle at the instant a spark is seen to enter at K.

Fig. 92.



In this experiment we have a type, or exemplification, of the mode in which electro-dynamic action may be propagated through both non-conducting and conducting bodies, showing that there is no necessity for the supposition that the disturbed electric matter constituting a spark, which appears to enter one end of a telegraphic wire, absolutely traverses the whole length of it, as a bullet traverses the tube of a gun-barrel on the discharge of a gun. From this experiment it is evident that the electro-dynamic impulses are not propagated by the momentum of the moving electric matter, as we shall presently have occasion to show. The preceding facts lead to the conclusion that electric conduction is the propagation of changes of polarization.

The "conduction of electricity" has been deemed one of the characteristic properties, which constitutes a test of the metallic nature of elementary substances. This fact appears, therefore, to show that the groupings of the atoms of metals become readily electro-polarized throughout the whole extent of the mass. Non-conducting substances become electro-polarized only to a very limited extent, as exhibited in the experiment with the plate of non-conducting glass; and hence it is necessary for them to be alternated with metals, which become readily electro-polarized; the electro-dynamic action may then be propagated readily.

These experiments serve beautifully to illustrate the polarizations of non-conducting bodies by disturbing the natural static condition of equilibrum of the electric fluid extisting in connection therewith; and also to illustrate the fact, that the comparative conducting powers of the sixty various kinds of elementary substances depend on the relative endowment or faculty of becoming more or less readily polarized by the continuous excitation of the sun.

That the propagation of electro-dynamic action throughout extended conducting bodies, is attended with a disturbance of the electric matter naturally existing in connection therewith, has just been illustrated by the preceding figure. A spark escapes from the knob L, at the instant a spark enters at K. So in using a *long* piece of conducting wire connected with a battery circuit, the same electro-polarization is propagated throughout the whole extent of it.

Professor Henry found that a brilliant spark and powerful shock occurred at the remote end of a long wire at the instant of making contact, when both of the phenomena were very feebly developed with a *short* piece of wire.* At the instant of breaking contact, similar phenomena again occurred, thus leading to the supposition that a movement of electric matter naturally in a state of rest in connection with the conducting wire must have been induced by the polarization of the continuous series of its component atoms, in an ebbing and flowing tidal wave, as exhibited in the operation of a magneto-electric machine.

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* Silliman's Journal, 1832.

Professor Henry found, "when sparks are thrown from an electric machine on the middle of a lightning rod, the electricity does not tend to pass silently into the earth: on the contrary, a spark can be drawn from every part of the rod,—even from that near the earth. This mode of propagation of electric action has been termed "lateral discharge."

The preceding experiment triumphantly decided a scientific controversy on the question of lateral discharges from conductors struck by lightning, which was agitated a few years ago. But as these lateral discharges are comparatively trifling in violence, when compared with the main discharges, although sometimes sufficient to fire gunpowder in a powder-house, they do not essentially impair the efficiency of lightning-rods to protect from personal injury the occupants of buildings and ships.

Professor Faraday observes (Experimental Researches, 1067), As the length of the connecting wire increases, the spark becomes proportionally brighter; until the length is extremely extended. The resistance offered by the metal as a conductor then begins to interfere.

In experimenting with a wire two or three hundred feet long, connected with a single battery cell of a zinc plate exposing a surface of one square foot to the acid solution, a bright spark and shock is producible when the current is suddenly stopped or reinstated. With the same battery the intensity of the shocks continued to increase, until the length of the connecting wire was extended to five or six hundred feet; after which length was exceeded, a diminution occurred.

It thus appears, that the same galvanic battery which will neither elicit a shock or spark when the current is sent through a short piece of conducting wire, will produce energetically both of these phenomena, when a greater length of conducting wire, that is, when a greater extent of matter is substituted. In experimenting with the far extended wires of electrical telegraphs, these ebbing and recurrent tides of electricity produce such powerful shocks, when large batteries are used, as to render it very uncomfortable to receive them through the hands and arms.

The preceding facts serve to exhibit the excitation of electric matter existing in a state of rest in connection with bodies by the propagation of electro-dynamic action through them, or by the *polarization* of the atoms of a mass of matter, as this mode of action may be more briefly expressed.

It remains now to show that the polarization of one body, by propagating electro-dynamic action through the mass of its component atoms will disturb the electric matter existing in a state of rest in all adjacent masses of atoms, and produce this similar polarization.

In mechanically moving an excited body near another unexcited body, it has been shown that the electric matter existing in connection with both bodies becomes disturbed. So in causing the movement of the electric matter along a body at rest, extended near another similar body at rest, we have reason to anticipate that the electric matter existing in connection with both of such bodies must become similarly disturbed, and a consequent propagation of impulses through the medium of this disturbed electric matter must ensue.

This fact admits of very palpable illustration by arranging two bodies in a state of relative rest near each other, and by causing a movement of the electric matter in one of them. The electro-dynamic impulses are thus shown to be as readily propagated from one body to another through a space of intervening air, as when the two bodies are mechanically moved near each other with their environing atmosphere of electric matter, as has been recapitulated.

The propagation of action of electric currents across a space intervening between two conducting bodies, through the medium of the electric matter diffused throughout the atmosphere, appears to have been first noticed by Professor Faraday in the year 1832, and described in the "Annals of Philosophy," among the "proceedings of the Royal Institution."

"If two wires, A and B, be placed side by side, but not in contact, and a voltaic current be passed through A, there is instantly a current produced by induction in B, in the opposite direction. Although the principal current in it be continued, still the secondary current in B is not found to accompany it, for it ceases after the first moment; but when the principal current is stopped, then there is a secondary current produced in B, in the opposite direction to that first produced by the inductive action, or in the same direction as that of the principal current."

To illustrate this propagation of electro-dynamic action, we have only to refer again to the examples of excitation of electricity naturally existing in connection with bodies by the figure of the spiral coil of conducting wire inclosing in its multiplied circuits the piece of iron, N, S, page 247, figure 107, from which, in like manner, a spark is expelled to the adjacent knob, W, whenever the current from a galvanic apparatus is propagated through the circumambient coils; and to which, when a current is cut off, a spark appears to return. The first spark represents the initial secondary current; and the returning spark, which occurs between the knob, W, and the bar of iron, N, S, represents the terminal secondary current. More powerful shocks are producible by the electric surges excited from the bodies approximated to the one which serves as the pathway of the primary current, than from the conducting body conveying the primary current itself.

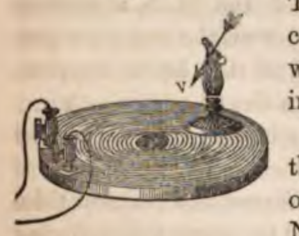
These secondary currents resemble effluent and refluent tides of momentary duration, appearing only at the instant the primary disturbing action is propagated through the approximated body, and reappearing in an opposite direction at the instant when it is stopped; that is, on each change of the polarization of the atoms, in accordance with the law established in the preceding pages.

The development of these initial and terminal secondary currents may be exhibited experimentally by arranging two pieces of wire, about sixty or eighty feet in length, near each other in parallel lines. On transmitting a galvanic current through one of the wires, a spark will be seen to pass from one end of the adjacent wire at the instant of the establishment of the galvanic current; and another spark will be seen at the instant of its termination.

The direction of the secondary current through the wire approximating the one serving as the pathway of the primary current, may be detected by connecting the two extreme ends by a fine wire environing a sewing needle used as an electroscope (fig. 43, page 247). But these initial and terminal secondary electric waves admit of being more effectively exhibited by winding a wire, covered with an insulating coating of varnished thread, into a compact spiral coil, or helix form. The primary disturbing current serves to act upon the electric matter of the wire in every repetition of its coils, which may be multiplied to several hundreds of circuits, so as to produce a brilliant spark, accompanied by audible snapping sounds.

The nearer the circuits are approximated, the more intense is the resultant disturbance of the state of rest of the electric matter in the form of powerful sparks and shocks. For this reason thin plates of metal are wound into coils like ribbons, as shown in the figure, and substituted in place of wires, approximated only at arcs of their circumferences. The sides of the ribbons of metal are of course to be insulated from actual contact with each other by an intervening coating of silk or varnish.

Fig. 93.

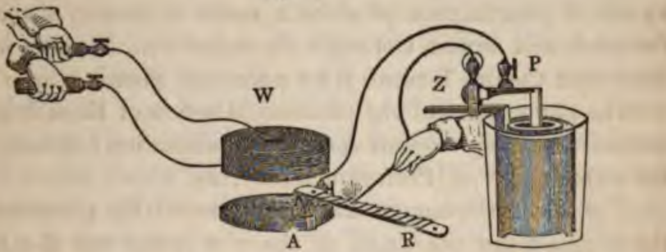


By using a coil of this copper fillet of the width of an inch, and of the length of two hundred and thirty-four feet, Mr. Noad states that a pair of zinc and copper battery plates of only $\frac{1}{6}$th of an inch in length, and $\frac{1}{25}$th of an inch in width, were adequate to propagating sufficient electro-dynamic action to become manifest in sparks, on rapidly breaking and renewing the contact with the battery circuit; and with a large battery very brilliant sparks were visible, and the snapping sounds were audible in distant apartments of the building, even when the intervening doors were closed. The mercury in the connecting cups was also decomposed, and evolved in copious fumes by these rapidly-vibrating surges of electro-polarizations.

Although a single ribbon of metal is employed in the preceding experiment, yet it is to be noticed that the electrical relationship or proximity of one coil to the other serves to produce reciprocal developments of electrical excitation.

The secondary *initial* and *terminal* currents admit of being more distinctly and separately exhibited by means of the employment of two ribbon coils, as experimentally practised by Professor Henry. This arrangement is shown in the annexed figure. A, represents a ribbon coil, about one hundred feet long, and R, a common steel rasp, united with one end of the copper ribbon coil, on one of the connecting cups of which it rests. In the other connecting cup of the ribbon coil, is inserted a wire, communicating with the pole of a battery at P.

Fig. 94.



The hand of the operator is exhibited in the figure, as holding a conducting wire, connected at one end with the cup, Z, whilst the other end is drawn over the ridges of the rasp to complete the circuit of the battery current through the ribbon coil, A.

By this contrivance a more rapid succession of contacts and breakages of contact is effected mechanically by the passing of the end of the wire over the successive furrows and ridges of the rasp, than could possibly be accomplished by lifting and dropping the end of the wire by the fingers.

Upon the coil, A, is imposed another similar coil, W, which may be insulated from A by a plate of glass. To propagate the action of the shocks of the secondary currents excited in W by the inductive action of the primary current transmitted through A, the two ends of wires connected with the ends of the ribbon coil may be grasped in the hands, as exhibited in the figure. To insure perfect contact with the wire, the precaution of wetting the hands should be taken.

It is manifest, that by drawing the point of the connecting wire over the ridges of the rasp, a very rapid succession of contacts and breakages occur; whereby at one instant the current is sent through the coil, A, and at the next instant, whilst the point of the connecting wire is passing over an intervening furrow of the rasp, the current is cut off. It consequently follows, that at one instant the insulated coil, W, is electro-polarized by the inductive action of the current transmitted through the approximated coil, A; and at the next instant, this electro-polarization ceases. Thus, in rapid succession these receding and returning waves of polarizations produce a series of powerful shocks in the arms and breast, although the upper coil, W, may be insulated from the one beneath it by a sheet of glass.

The phenomena of the mechanical action of these *initial* and *terminal secondary currents* have been elaborately developed by the experiments of Professor Henry, by whose labors the science of electro-dynamics has been essentially advanced. He states, that when the length of the wire in the coil of a helix is increased, the power of the battery continuing uniformly the same, the intensity of the shock is correspondingly increased, until finally, the greater resistance opposed by very long wires, to the passage of the primary exciting current, serves to counteract, and even to reduce, the intensity of the shocks. Whilst the shock from a small battery is increased by the intervention even of a short ribbon coil, that from a large one did not appear to be much increased thereby. But when the length of the coiled wire is increased in proportion to the increase of the size of the battery, then the intensity of the shocks becomes surprisingly increased.

Professor Henry found that the current from a battery of 16 pairs of Cruikshank's arrangement, which produced only very feeble effects when transmitted through a short ribbon coil, gave shocks *too strong to be taken through the body*, when transmitted through a spiral coil of copper wire $\frac{1}{16}$th of an inch in diameter, and five miles long.

Whilst the intensity of the shocks of the secondary currents is thus increased by the extension of the length of the wire, the power of the primary current becomes correspondingly decreased as tested by its power of heating fine wires red-hot, and of deflagrating thin sheets of gold leaf, and of other metals.

In the preceding figure, when the coil A consisted of about 300 feet of copper ribbon, of the width of an inch and a half, and W of a helix of copper wire five miles long, Professor Henry found that shocks might be obtained when the coils were *four feet* apart.

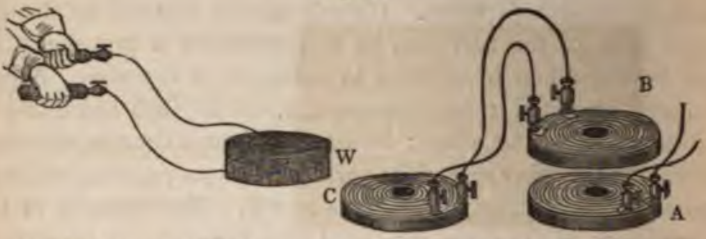
In order to render this experiment more astonishing and impressive, the Professor caused the inductive action to be propagated through a partition wall interposed between two rooms. He suspended a coil of about 100 feet of ribbon-shaped copper fillet against the wall, or preferably against a thin wooden door, or wooden partition. Directly against this coil on the opposite side of the partition, he suspended, on a peg, a similar coil, having a handle soldered to each end of the wire. A person was requested to take the handles, one in each hand, and to lift the coil from its place; whilst at the same time an operator, unseen on the other side of the partition, was propagating an intermitted current through the opposite coil. The intensity of the convulsions of the arms, combined with the alarming mystery of the invisible cause, overpowered the resolution of timid persons, and deterred them from persevering in the attempt.

The separation of the coils by an interval of space of air, and by the partition, renders it manifest that the disturbance of the electric matter is induced in the insulated coil, by the action of the disturbed electric matter in the distant coil; whilst the intensity of the original exciting battery current is so slight as scarcely to produce any perceptible sensation, when propagated directly through the arms of the experimenter.

It may here be noticed that the transmission of a regular current of galvanic electricity through the body, from a powerful battery, does not produce a very violent action. It excites the sensation of a dull oppressive pain of the joints or limbs, and writhing contortions of the muscles, through which it passes. At the moment of the commencement, or of the termination of the current, a shock is experienced, as has just been described.

It was found, also, by Professor Henry, that these *secondary* currents produce the effect of inducing *tertiary* currents, as is illustrated by the following experiment. Cause a *primary* current from a galvanic apparatus to be transmitted through a spiral coil, A, and place above it another spiral coil, B. Arrange conducting wires so as to connect the ends of the coil, B, with the third spiral coil, C, removed to such a distance from A as not to be affected by the primary current therein. The secondary current thus induced to flow through C, will induce also a *tertiary* current in the spiral coil, W, of sufficient intensity to give shocks, whenever the circuit in A is interrupted and re-established. And in like manner subordinate currents of *fourth and fifth orders*, even up to the seventh, have been discovered to be induced in a series of these coils!

Fig. 95.



In the course of his experiments, Professor Henry ascertained that there is an alternation in the direction of the currents of the several orders, commencing with the secondary, as exhibited by the similar and dissimilar directions of the arrow heads in the following arrangement.

Fig 96.

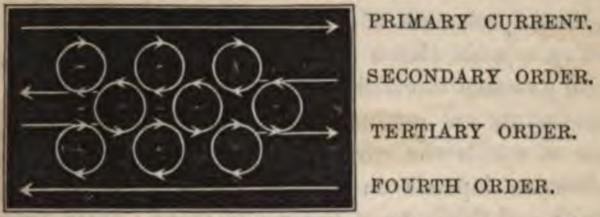
		At the beginning.	At the ending.
Running	Current,		
Secondary,	"	→	←
Tertiary,	"	←	→
Fourth order,	"	→	←
Fifth, "	"	←	→
Sixth, "	"	→	←
Seventh, "	"	←	←

The interposition of a circular metallic plate between the approximated wire coils, serves nearly to neutralize the shocks; but if a notch be cut in the plate from the edge to the centre, the shocks will be but little reduced.

As oppositely propagated electro-dynamic impulses produce the phenomena of the reciprocal repulsion of approximated atoms and masses, the alternately reversed directions exhibited in the preceding diagram afford sufficient explanation of the sudden dissipation of solid bodies by violent electrical action in the discharges of Leyden batteries, and of lightning. The sudden excitation of their alternately opposite actions really constitutes the opposite polarizations of bodies.

The alternate reversal of the polarizations of approximated atoms and masses at their polar axis, appears to be the necessary result of the reduction of their equatorial currents to a similar direction by the overpowering influence of the primary current, as represented in the annexed diagram.

Fig. 97.



The upper arrow represents the primary, or exciting current; and the alternate directions may be deemed to be a resolution of the molecular polarization into a new order of arrangement, in which the equatorial action is augmented in intensity in proportion as the polar action is diminished or reversed. This system of the alternate propagation of the electric action in opposite directions, appears to be the only rational mode of explaining this otherwise mysterious phenomenon.

When secondary polarizations are momentarily induced by the action of an intermitted primary current, they instantaneously become restored by the recoiling natural molecular polarizations. The consequence of this action of every exciting current is the development of two changes of polarization, one of which is simultaneous with the commencement of the exciting action, and the other with the termination of it.

And again, as each initial and terminal polarization of an excited coil is capable of propagating action to another adjacent coil, it follows that each secondary polarization becomes again propagated to produce a tertiary polarization in the third coil; and so on throughout a series of approximated coils, or bodies. This system illustrates the diffusion of mechanical impulses through the medium of electric matter.

The reversals of polarizations are so instantaneously effected, that the action on a galvanometer is too brief to allow time for the mass of the magnetic needle to be put in motion thereby; as occurs when a rifle ball passes through a door without stirring it on its hinges.

To detect these brief propagations of electro-dynamic action, a sewing needle is used for a galvanoscope, as described at page 247. But if the needle be left in the wire coil until both the initial and terminal polarizations have taken place, the oppositely directed action and reaction will neutralize each other, and no discoverable results will be detected by this electroscopic test.

In the experiments of Professor Henry on the excitation of *alternating opposite electric currents*, "the results with ordinary, and with galvanic electricity, prove to be similar;" and "when the conductors are gradually separated, there is, it appears, a distance at which the current begins to change its direction. This distance depends on the amount of the discharge, and on the length and thickness of the conductors." With a battery of eight half-gallon jars, and parallel wires of about ten feet long, the Professor found the change in the direction did not take place at a less distance than from twelve to fifteen inches.

The alternations of the directions of a series of secondary, tertiary, and other subordinate currents, afford a satisfactory explanation of the strongest objection that was once urged against the general truthfulness of electro-dynamic science. Previously to the discovery of the alternations of oppositely directed secondary and tertiary currents in bodies approximated to the action of a primary one, Mr. Savary had discovered facts of the uncertain varying magnetic polarity, which he found to be imparted to a series of needles arranged at different distances from a primary current. This fact was deemed a proof of a capriciousness in the action of electric currents, which admitted of the application of no certain law of calculation. When steel needles were placed at different distances, the N. polarity appeared to be incited by the electric current sometimes at one of the ends of the needles, and sometimes at the other.

But these apparently anomalous and contradictory results, which were at one time a stumbling-block in the way of investigating this branch of science, since the admirable discovery of alternating opposite currents, are now assumed to afford the most conclusive proof of the establishment of systematic laws of electro-dynamic action.

Thus we are impressively taught the lesson of the universal exactness of the operation of all the principles of action of natural motive powers through the medium of electricity; and that even the most contradictory facts may be in reality the most conclusive proofs of the unerring truthfulness of the Laws of Nature.

By the sudden opening and closing of the galvanic circuit, it has been noticed that *sounds are produced* throughout the component atoms of a metallic rod, and the coils of wire wound about an electro-magnet. These sounds resemble those produced by striking a rod upon one of its ends, as stated by Professor Henry. Similar sounds are producible in iron bars suddenly subjected to magnetization and demagnetization, by establishing and cutting off in rapid succession galvanic currents about the coils of wire inclosing them. This remarkable kind of noise may be supposed to originate from the electro-polar changes among the constituent atoms of the mass of iron which have just been described.

That the preceding sudden reversals of the propagation of electro-dynamic action throughout a series of particles of contiguous atoms must produce movements of them, appears to be a rational conclusion. In examining wires which had been subjected to use for a considerable time in repeating these experiments, I have found them to be rendered brittle, and to exhibit a more crystalline appearance of fractured parts.

This result, indeed, appears to be only the incipient stage of a partial change of groupings of all atoms, which occurs when subjected to intense propagation of electro-dynamic action. The process of electro-metallurgy is practically founded on the reversal of the polarization of atoms at one pole of a galvanic circuit, and the consequent movement of them therefrom to the opposite pole, where the polarization and consequent crystallization is re-established. The same result is also discoverable to take place in the movement of the atoms of the point of a wire, or of charcoal, used to exhibit electric light, from the transmission of a current across an intervening space between the two battery poles. The particles of metal and charcoal are always found to be removed from one point and attached to the other. The former, for this reason, always become longer, and the latter become shorter. The actual movements of atoms at sensible distances are thus detected. That their movements at insensible distances are caused by changes of polarization, is probable.

The remarkable facility of propagation of mechanical action through the medium of electric matter, by inducing the electro-polarization of series of atoms constituting conducting bodies, has been illustrated by many interesting experiments. In the Proceedings of the American Philosophical Society, in the year 1843, Professor Henry has published instructive notices and facts of the inductive propagation of electro-dynamic action to remote distances by the discharges of Leyden jars, and of flashes of lightning. The following experiments demonstrate that the electro-polarization of a conducting wire is propagated not only through floors of rooms and other intervening bodies, to induce their electro-polarization, but even through great distances of intervening atmosphere.

"A copper wire was suspended by silk strings around the ceiling of an upper room, so as to form a parallelogram of about sixty feet by thirty on the sides; and in the cellar of the same building, immediately below, another parallelogram of the same dimensions was placed. When a spark from an electrical machine was transmitted through the upper parallelogram, an induced current was developed in the lower one, sufficiently powerful to magnetize needles, although two floors intervened, and the conductors were separated to the distance of thirty feet. In this experiment no electricity passed through the floors from one conductor to the other; the effect was entirely due to the repulsive action of the electricity in motion in the upper wire on the electricity of the lower. In another experiment, two wires, about four hundred feet long, were stretched parallel to each other between two buildings; a spark of electricity sent through one produced a current in the other, though the two were separated to the distance of three hundred feet; and from all the experiments it was concluded that the distance might be indefinitely increased, provided the wires were lengthened in a corresponding ratio."

To prove that the same effect is produced by the action of the electrical discharges in the form of lightning in the heavens, Professor Henry made the following modification of the foregoing arrangement.

"One of the wires was removed, and the other so lengthened at one end, as to pass into my study, and thence through a cellar window into an adjoining well. With every flash of lightning which took place in the heavens, *within at least a circle of twenty miles* around Princeton, sewing needles were magnetized in the study by the induced current developed by the wire."

"Being led from these results to infer, that induced currents must traverse the line of a railroad, I found that sparks were seen at the breaks in the continuity of the rails, at every flash of a distant thunder-cloud."

He remarks that "similar effects, but in a greater degree, must be produced on the wire of the telegraph by every discharge in the heavens; and the phenomena which I witnessed at the telegraph office in Philadelphia, were, I am sure, of this kind. The operators at each end of the line announced at the same time a storm in Washington, and another at Jersey City. The portion of the circuit of the wire which entered the building, and was connected with one pole of the galvanic battery, happened to pass within the distance of less than an inch of the wire which served to form the connection of the other pole with the earth. Across this space, at an interval of every few minutes, a series of sparks, in rapid succession, were observed to pass; and when one of the storms arrived so near Philadelphia, that the lightning could be seen, each series of sparks were found to be simultaneous with a distant flash in the heavens. Now we cannot suppose for a moment that the wire was actually struck at the time each flash took place; and, indeed, it was observable that the sparks were produced when the cloud and flash were at the distance of several miles to the east of the line of the wire. The inevitable conclusion is, that all the exhibition of electrical phenomena, witnessed during the afternoon, was purely the *effect of induction*, or the mere disturbance of the natural electricity of the wire, without any transfer of the fluid from the cloud at a distance to the apparatus."

"The discharge between the portions of the wire continued for more than an hour, when the effect became so powerful, that the superintendent, alarmed for the safety of the building, connected the long wire with the city gas pipes, and thus transmitted the current silently to the ground."

Professor Page gives the result of one of his experiments, made with a galvanoscope, connected with the metallic roofing of the Patent Office building, containing an area of twenty-two thousand feet of surface exposed to the atmosphere, and a plate of copper buried in the earth adjacent thereto. "I may safely say that the needle is affected by a flash of lightning one hundred miles distant." He also observes,* "during heavy storms, a flash of lightning, twenty miles distant from the wires of Morse's Magnetic Telegraph, will induce electricity in the wire sufficient to operate the magnets and work the telegraph, sometimes recording several signals. A flash of lightning in Baltimore, forty miles distant from Washington, will operate the magnet at that end of the line."

The preceding facts demonstrate, that by disturbing the electric matter existing in connection with any one body situated near other bodies, disturbances are produced in their respective electrical atmospheres, inducing undulatory waves, or actual currents, according to the intensity and continuance of the disturbance.

In order to exhibit the experiments of secondary currents, and the consequent shocks and sparks, without the necessity for the manual labor of drawing the end of the conducting wire over the ridges of a rasp, as described in the preceding pages, various kinds of machines have been invented for the express purpose of breaking and renewing the contact of the ends of the conducting wires with extreme rapidity. This result has been accomplished by means of clockwork moved by clock springs, and even by mechanisms operated by self-acting electro-dynamic agency. Some of these machines are worthy of description, as developing important facts; the mode of action of the secondary currents of electricity induced in all conducting bodies when arranged in proximity to each other.

These machines have been designated by the name of ELECTROTOMES, from the original Greek words, ELECTRON, *electricity*, and TEMM[illegible] *c off*.

A self-acting electrotome, contrived with movable parts, to be operated by the motive power of the battery current itself, is now manufactured, for applying very conveniently a series of intense shocks for medical purposes.

The primary current from a galvanic battery or magneto-electrical machine, is propagated through coils of insulated or coated wire wound about the two vertical ends of a bar of iron, bended to the form of the letter U, as shown in the figure; whereby this piece of iron is converted into a temporary electro-magnet, whilst the current circulates about it, as described at page 246. Directly above the tops of the prongs of this temporary magnet is a piece of iron, serving as a *keeper* or *armature*, sustained by a spring, which allows freedom of motion to the cross-bar to descend in obedience to the attractive impulses, and causes it to rise from the ends or poles of the U shaped bar, at the moment the current ceases to circulate about the coils. The distance to which the cross-bar is lifted by the spring above the tops of the ends or poles of the electro-magnet, is adjusted by the screw, S, which depresses the spring by the contact of its lower end therewith.

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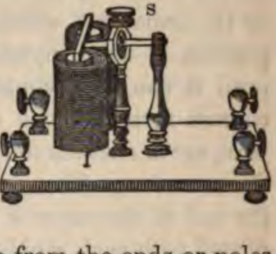
* American Journal of Science and Arts. September, 1846.

Fig. 98.



The screw-cups at one end of the machine are designed for receiving the conducting wires of the primary current from the battery, and are connected by wires beneath the base-board with the ends of the spiral coils wound about the bended iron bar. Leaving the extremity of the wire of the coils, the current flows beneath the base-board into the brass pillar, and through the screw S and flexible spring to the adjacent brass pillar, to which one end of this spring is attached. Descending this pillar the current is transmitted by wires beneath the base-board to one of the screw-cups at the end farthest from the electro-magnet, and thence through the circuit of the arms of the experimenter or through a connecting wire uniting the two screw-cups to the fourth cup adjacent to the electro-magnet, from whence it completes its circuit to the exciting battery.

By this arrangement the electric shocks are propagated from the same wire which transmits the primary current.

When the connection with an excited battery is formed, the current transmitted about the coils environing the U shaped bar of iron converts this bar into an electro-magnet. The armature is instantaneously drawn down in contact with the poles adjacent thereto, depressing the flexible steel spring from its pressure and contact with the point of the screw, S. Its contact therewith is thus broken; and consequently, the further circulation of the electric current about the wire coils wound around the poles of the U magnet is cut off. The immediate effect of thus cutting off the current is the cessation of further electro-magnetic action on the armature; which, on being released from its constrained position is urged upwards by the action of the flexible spring, until it comes in contact with the end of the screw, S. This contact restores again the circulation of the current, which, in turn, again restores the electro-magnetic action, and brings down the armature. The separation of the spring from contact with the end of the screw is again produced, and this operation is repeated with such rapidity as to produce a humming sound, like that made by the rapidly-vibrating wings of a bee.

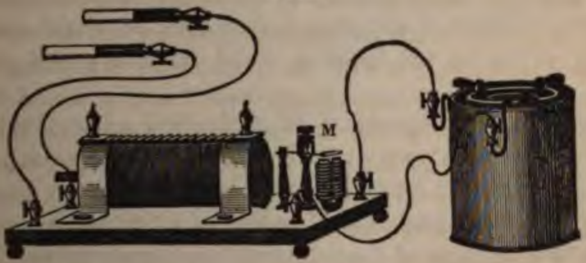
This instrument I have found to serve admirably to illustrate to an audience by *sounds*, the counterpart of the visible characters employed to represent the letters of the alphabet in the electro-magnetic telegraph of Mr. Morse. Electro-telegraphic communications may thus be addressed to the electroscopic nerves of the ear, instead of those of the eye.

To accomplish this, detach one end of the wire from the screw-cup connected with the pole of the battery, and hold it for a longer or shorter time in contact with the connecting cup. A correspondingly longer or shorter duration of this audible buzzing sound is produced, corresponding with dots and dashes, made with the pencil or style of the electro-magnetic telegraph. Thus, by a brief touch or contact of the end of the conducting wire held in the fingers with the connecting cup forming the pole of the battery, a correspondingly brief buzzing sound becomes audible, equivalent to the dot or mark (.) made on the slip of paper by the point of the wire or style of the electro-telegraphic instrument; and by a prolonged touch, or contact, a continuous audible buzzing sound is sustained, corresponding to the dash (—). A conversation may thus be carried on in the dark by audible sounds between persons at remote telegraphic stations, by the simple little instrument, substituted in place of a recording telegraphic apparatus.

To illustrate the facility of propagating electro-dynamic action to reach the material nerves of the ear, instead of those of the eye, as in the recording telegraphs, to transmit intelligible communications between mind and mind, it is only necessary to agree upon conventional prolongations of sound to represent the letters of the alphabet. Thus, let a momentary buzzing sound represent A, two similarly momentary sounds quickly repeated, the letter B, and a prolonged sound, the letter C. Every person in a large audience will then comprehend readily, that if a prolonged sound be heard correspondingly with a dash (—), and momentary sounds (.) (..), that a "CAB" is called for through the medium of electric matter, and with an utterance that may be supposed to have traversed a space of scores of miles. The functions of the tongue are thus performed through the medium of electric matter in accomplishing intercourse between intelligent beings.

If it be required to propagate electro-dynamic action to produce the most overpowering effects on the material nerves of feeling of sentient beings, and the most violent involuntary muscular contractions and consequent developments of animal motive power, such as the utmost energies of the volitions cannot restrain, the following described little Electrotome may be employed. It differs from the preceding one, by substituting for the single coil, from which the electric matter is disturbed, a double coil, the one wound over the other, to act on the principle of exciting secondary currents, as exhibited in figure 94.

Fig. 99.



The double helix, instead of being arranged vertically, as shown in the preceding instrument, is secured by two brass bands to the base-board. The electro-magnet is denoted by M. The vibrating iron is supported over the two poles by an elastic spring arranged like that shown in the preceding figure. The outer helix coil is wound over an inner one, and is insulated therefrom.

The electric shocks are transmitted through the two metallic handles to the arms and chest of the patient, or to any specific part of the body, through which it may be desirable to transmit electro-dynamic excitation for medical treatment.

In this instrument, the electricity which passes through the handle, is not the primary battery current. The primary battery current is caused to make a rapidly intermitted circuit through the coarse wire coil surrounding the electro-magnet, M, and then through the coils of the same wire, inclosed by the outer fine wire helix coil. The ebbing and flowing currents of the electricity naturally existing in a state of rest in connection with the outer helix coil are induced to flow back and forth in surging tides through the handles, as shown in the figure, to the body of the experimenter, and to cause the shocks.

The intensity of the excitation is greatly augmented on inserting a rod of iron or bundle of wires within the inner helix, to react thereon. When the bundle of wires is entirely thrust into the interior of this helix coil they become converted into temporary magnets, and react on the wire-coils, augmenting the intensity of the shocks until they become perfectly benumbing, and all power of commanding the movements of the arms is lost. Indeed the writhing contortions of the muscles are so violent, when a powerful battery is used, that the patient is unable to relax his grasp of the handles, and continues involuntarily to endure the infliction of the pain, from which he would gladly escape by dropping the handles, could he loosen his grasp of them.

Although the propagation of mechanical action through the medium of electric matter may be accomplished by the polarization of an extended series of atoms, as has just been illustrated, yet the process so much resembles that of a continuous current of a fluid, that the idea of "conduction" of electricity has become inseparably connected with the idea of this propagation. As remarked by Professor Faraday, "So long as the term *current*, and the word *electro-dynamic*, are used to express the relation of the electric forces, in which *progression* of either fluids or effects are supposed to occur, so long will the idea of velocity be associated with them, particularly if electricity be deemed a fluid substance."

Without at present entering further upon the discussion of the question of the actual modes of propagation of electro-dynamic action through a series of contiguous atoms, the facts of this propagation will be briefly considered.

PROPAGATION OF ELECTRO-DYNAMIC ACTION THROUGH A SERIES OF CONTINUOUS ATOMS CONSTITUTING THE PHENOMENON OF CONDUCTION.

Conductors.—Considering that all bodies, which serve to propagate impulses of mechanical force through the medium of electric matter, represent simply pathways of electric currents, Professor Faraday has applied the term ELECTRODE (from the Greek words ELECTRON, signifying electricity, and ODOS, a *way*, or *path*) to denote conducting bodies.

To that particular end of the Electrode at which the current is supposed to enter, he has given the name of ANODE,—derived from Greek words signifying *upward*, and *way*, in figurative allusion to the advance of the rising sun. And the term CATHODE, or *downward way*, has been similarly adopted by him as a suitable term to denote the point of departure of the current from a conducting body, as emblematically represented by the setting sun.

But if we consider a conducting body to be made up of a series of atoms or conjoined parts, it is manifest that every section is a distinct electrode, each representing a distinct horizon, and having its distinct anode and cathode, or rising and setting sun. This virtually constitutes the polarization of matter.

Other writers have employed various other terms to denote these same relative parts of conducting bodies, such as Negative and Positive poles, and *Zincode* and *Platinode* poles, in reference to the metallic battery plates.

But considering that all atoms as well as masses of terrestrial matter merely serve passively to receive and propagate impulses of mechanical force through the medium of electric matter by their polarization, as has been premised, these opposite initial and terminal points simply represent the approximated parts, between which the mechanical *action* and *reaction* take place.

It would therefore be preferable to adopt the idea of the simple propagation and reception of mechanical impulses constituting the phenomenon of polarization, through the medium of the electric matter existing in connection with groupings of atoms, instead of the idea of regularly flowing currents from atom to atom, and mass to mass, throughout the whole length of conducting wires and other bodies.

The first notice of the conducting powers of various bodies appears to have been taken by Stephen Gray in 1720. He announced the discovery, that by means of metallic bodies, the communication of electrical action might be transmitted to a distance of 886 feet! Subsequent experiments have established the belief that this action admits of being extended to the circuit of the earth.

Metals and charcoal, it has been stated, "are the only true conductors; as it is through them alone that galvanic currents are propagated without producing change. In passing through all compound substances, such as solutions of salts, water, and other fluids, the conduction is effected only by virtue of the decomposition of these substances."

TABLE OF CODUCTING SUBSTANCES.

The following table exhibits the comparative facilities afforded by groupings of different kinds of simple and compound elementary atoms in propagating electro-dynamic action. The several substances are arranged in the order of their conducting powers.

Silver,
Copper,
Brass,
Iron,
Platinum,
Charcoal,
Steam,
Rarefied air,
Earth and stones in their stratified states,
Dry metallic oxides,
Oils,
Lump sugar,
Leather,
Dry paper,
Cotton,
Feathers,
Hair,

Dilute acids,
Solutions of salts,
Metallic ores,
Animal fluids,
Pure water,
Ice above—13° Fa'ht,
Snow,
Living vegetables and animals,
Flame and smoke,

Vegetable and animal ashes,
Ice below—'13,
Lime,
India-rubber,
Siliceous stones, } in proporion to hardness,
Argillaceous " } in proporion to hardness,
Porcelain,
Baked wood,
Dry air and gases,

Wool,
Silk,
Diamond,
Glass,
Wax,
Sulphur,
Resin,
Amber,
Gum lac.

Becquerel has given the following experimental results as the comparative conducting powers of various metals.

Copper,	100,	Gold,	93·6,	Silver,	37·6,
Zinc,	28·5,	Platinum,	16·4,	Iron,	15·8,
Tin,	15·5,	Lead,	8·3.		

The different relative scale of the powers of some of the principal kinds of metals as conductors of galvanic electricity, has been given by Mr. Daniel Davis, as follows:

Copper,	16·220,	Silver,	15·600,	Brass,	12·354,
Gold,	11·580,	Iron,	7·800,	Platinum,	7·390.

PROPAGATION OF THE ELECTRO-DYNAMIC ACTION FROM GALVANIC BATTERIES THROUGH CONDUCTING BODIES.

The term "current" has usually been applied to designate the propagation of electro-dynamic action from galvanic batteries. This term represents a prolonged propagation of electric action, such as occurs when the discharge of a Leyden battery is prolonged to an appreciable period of time by employing an imperfect conductor, composed of a thread moistened in salt water, to serve as the medium for the transmission of the polarized action and reaction between the internal and external coating.

The conducting powers of wires of various lengths and diameters, have been experimentally tested by Pouillet, Becquerel, Christie, Ohm, Fechner, Barlow, Cumming, and Ritchie. Different estimates have been published by them of the conducting powers of wires composed of the same kinds of metals.

Ohm and Fechner have affirmed the law of conduction to be "inversely as their lengths, and directly as their sections, or as the squares of their diameters;" whilst others of them affirm the conductibility of bodies to be inversely proportionate to the squares of the length, and directly proportionate to the diameter of the wires.

So rapidly diminished becomes the intensity of the electro-dynamic action of the current from a galvanic battery when transmitted through far-extended wires, that it was long a popular opinion that galvanic electricity could not be effectively employed for transmitting electro-mechanical impulses to remote distances along wires for establishing telegraphic communications. But by increasing the number of galvanic batteries employed, the fact was ascertained by Wheatstone, that the intensity of the current could be increased to such an extent as to turn the freely-movable needles of galvanometers at very remote distances, so as to render this mode of transmitting electro-mechanical impulses available through the far-extended lines of conducting wires used for telegraphic purposes.

When the electro-dynamic action of galvanic batteries was first applied to propagate electro-mechanical impulses through long wires, in order to induce magnetic excitation in pieces of soft iron, as has been described, it was discovered that such a rapid diminution of the excitation ensued, that Professors Barlow, Green, and Daniells, affirmed that the most energetic batteries are inadequate to propagate electro-dynamic action through very considerable lengths of conducting wires, availably for developing magnetic phenomena in pieces of soft iron placed within the spiral coils of the remote end of the wire.

In the year 1837 Professor Morse entered a caveat for a patent right to employ the electro-dynamic power developed by converting a piece of soft iron into a temporary magnet, by means of propagating a galvanic current about it as has been exhibited by the vibrating armature of the machine described at page 389. Although the experiment succeeded satisfactorily when the galvanic battery was placed on the table by the side of the apparatus, yet the rapid diminution of the power, propagated from the battery through the medium of electric matter to remote distances at the extreme ends of far extended wires, was still a subject of doubt and uncertainty. Although Wheatstone had led the way in establishing the fact of the propagation of an electro-motive power adequate to turning a compass needle on its pivot, yet the fact of the power of a battery to propagate effective impulses to cause a piece of soft iron to develope effective mechanical action still remained to be established experimentally.

It appears that Professor Morse first succeeded in establishing the practicability of propagating mechanical action in this way through an extent of about half a mile of conducting wire, with sufficient power to inscribe marks on a piece of paper, which he drew forward beneath a pencil pressed against it by electro-motive power.

Being still doubtful of the actual feasibility of transmitting galvanic currents to act efficiently at *remote distances* for developing the mechanical force of electro-magnetic impulses in the pieces of soft iron, when used for telegraphic purposes, Professor Morse addressed a letter, in the year 1838, to the Committee on Commerce of the United States, House of Representatives, soliciting aid to enable him to test experimentally this fact; (see Vail's Am. Telegraph, page 80;) observing, "I think it desirable that an experiment on a somewhat extended scale should be made, to test both the practicability and the facility of communicating intelligence for at least one hundred miles."

An appropriation of thirty thousand dollars enabled him first to test the important fact, that mechanical action could be transmitted through the medium of electric matter to remote distances from galvanic batteries, as stated in a communication in Silliman's Journal, published in August, 1843.

At this juncture, the very powerful arrangement of Groves's battery was fortunately introduced into use, which probably served essentially to determine the success of Professor Morse's first experiment with the funds furnished by the government of the United States. By means of a combined arrangement of fifty cells of Groves's galvanic battery, a mechanical action was first successfully propagated through the medium of electric matter to a distance of thirty-three miles from Washington toward Baltimore, whereby a weight of $\frac{1}{7}$th of an ounce could be instantaneously lifted and dropped, at the pleasure of the operator in Washington.

By the conjoint labors of Professors Morse and Fisher, the fact appears to have been first verified as a law, "that whilst the distance was increased in arithmetical ratio, an addition to the series of galvanic pairs of plates increased the magnetic power in a geometric ratio." Hence it was concluded "that the practicability of transmitting currents to any accessible distances is relieved from all scientific objections."

An historical account of the interesting discoveries of the electric telegraph will be presently detailed.

In communicating the results of Mr. Walker's experiments in propagating mechanical action along telegraphic wires beween Washington and St. Louis, Dr. Bache states in a communication to the American Association at Charleston, that the electro-dynamic action is propagated in the form of "hydro-galvanic waves" in both directions simultaneously, without interference. "As several successive syllables of sound may set out in succession from the same place, and be on their way at the same time to the listener at a distance, so also, when the telegraph line is long enough, several waves may be on their way from the signal station before the first one reaches the receiving station."

This account very exactly corresponds with the propagation of mechanical action by the undulatory waves of fluid water and air. On the surface of quiet waters the waves may be seen propagating the impulses simultaneously imparted to them from numerous disturbing causes, in equally numerous relative directions, the undulations crossing and recrossing each other, and even running in opposite directions, without interference. A similar result occurs in the propagation of impulses through the air in the modified form of sounds, which do not interfere with each other, however numerous the directions from which they may proceed, each one producing its peculiar action, or *tone*, as familiarly recognized in the use of combined musical instruments. The electric waves of polarization appear to be similarly propagated through the medium of the perfectly mobile electric matter by the waves of polarization of the atoms of the telegraphic wires.

When there is no gross matter to be polarized, and to direct the line of propagation, it becomes equally diffused, as in the void space of the heavens. This fact is most remarkably exemplified in the simultaneous propagation of electro-mechanical action from the myriads of stars profusely sprinkled throughout the depths of space, each one transmitting its distinct undulatory wave through the electric ether diffused throughout void space, and each inducing its distinct action on the electroscopic retina of the eye. The electro-dynamic action from the very remotest clusters of stars, however, become so blended together in the nebulous haze of the milky way, as to require the artificial aid of the telescope to concentrate the electro-dynamic impulses upon material nerves.

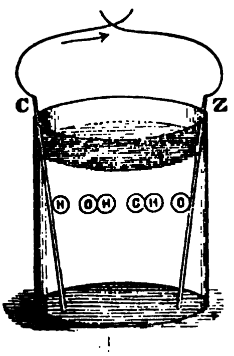
Conducting Powers of Fluids.

Freely movable atoms of fluids, interposed between the points of wires constituting electric circuits, become polarized, and various relative movements of them are found to occur. The atoms of atmospheric air become polarized, first, similarly, and then dissimilarly, and are first urged toward the excited pole, and then from it. The electro-dynamic action is propagated by direct mechanical impulses to the air in a breeze. Turpentine and other liquids exhibit very distinctly the currents toward and from the poles of a galvanic battery. But in most groupings of two or more kinds of molecules, the polarizations extend to the individual atoms, causing their separation from each other. The molecules of water, for instance, in propagating electro-mechanical impulses, become polarized, and the individual atoms of hydrogen and oxygen are thereby separated, the latter going to the positive pole, and the former to the negative pole. New orders or arrangements of polarizations are thus effected in liquid solutions of compound substances.

The theory was originally advanced by Grotthus, that electro-dynamic action is propagated through fluid compound substances by a succession of decompositions and recompositions of the series of molecules situated in the line between the poles of the galvanic apparatus, as illustrated in the following figure.

Supposing three molecules of water to be represented by the six small circles, representing three atoms each of oxygen and hydrogen, in a line between the opposite copper and zinc plates of a battery cell, the molecules become polarized by the action of the recoiling zinc; and the atom of oxygen, O, becomes urged toward the zinc plate, Z, and electro-dynamically united therewith, allowing the zinc plate to become restored to its natural polarization of an oxide of zinc or earthy ore.

Fig. 100.



On the reunion of this atom of oxygen with the zinc plate, it might be supposed that the bubble of hydrogen previously united therewith to constitute a molecule of water, would be set free in a bubble of gas to rise immediately to the surface of the liquid. But this result does not take place; on the contrary, the bubble of hydrogen gas appears in contact with the surface of the plate, C, across a considerable space of intervening liquid, as represented by the detached circle.

To explain this phenomenon, the same polarization has been considered to be extended throughout the series of molecules, so that at the instant the right hand atom, O, becomes polarized and urged toward the plate, Z, its twin atom becomes oppositely polarized and urged toward the left hand to become united with the atom, O, forming another molecule of water; and so on throughout the whole extent of the series of the molecules of water, until the last atom of hydrogen, having no atom of oxygen to become united with, is detached and set free to rise in a bubble of gas to the surface of the liquid in contact with the copper plate.

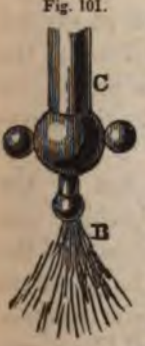
These reciprocal changes of the unions of different kinds of freely movable atoms in solutions have been designated by the term "Chemical Decomposition." The new order of polarization of the atoms, which simultaneously ensues, has been similarly designated by the term "Chemical Composition." It is manifest, in this case, that both of these phenomena of Chemical Decomposition, and of Chemical Composition, are the effects of a polarization produced by the propagation of mechanical action through the medium of electric matter. Hence the question of the *identity of Chemical and Electrical action* will hereafter be argued, when we recur to this subject in treating of CHEMICAL AFFINITY, as a source of Natural Motive Power.

PROPAGATION OF ELECTRO-MECHANICAL IMPULSES IN DISRUPTIVE DISCHARGES THROUGH THE AIR.

The facts of the propagation of mechanical action through the medium of electric matter, in the modified form of lightning and electric sparks, have been previously described. The investigation of the modes in which this action is propagated through the air is fraught with instructive information.

In his "Experimental Researches," Professor Faraday has classified the propagation of electro-dynamic action under three heads, viz., by *Disruption*, *Conduction*, and *Convection*. Conduction has just been considered as a modified form of inductive excitation, or of polarizations of a continuous series of atoms and masses. In the preceding classification by Professor Faraday, the electric matter appears to be regarded as transferable from one portion of matter to another. In treating of the Conducting Power of Fluids, it has been noticed that the molecules of air, turpentine, &c., on becoming polarized, are urged from the battery pole, thus propagating the electro-dynamic action in the modified form of mechanical movements of the atoms. These movements are considered as wafting the electric matter across a space occupied by air; and hence the term "Convective," has been applied to designate this mode of ferriage of electric matter, instead of its propagation by mechanical action through the medium of electric matter.

Fig. 101.



The term "disruptive" implies a breaking through, and is figuratively employed to denote the noisy discharges of lightning or electric sparks through the air. The silent luminous brushes darting forth from electrically excited bodies, as shown in the figure, also constitute another form of disruptive discharge.

When the disruptive discharge takes place through the vacuous space of a bell glass, as has been illustrated at page 60, it becomes reduced to lambent corruscations of varying intensity of action, producing equally varied electro-dynamic action on the material nerves of the eye, and correspondingly modified sensations or perceptions of various hues.

In treating of Conduction, the facts have been stated, that electro-dynamic action from a galvanic battery may be propagated through a great length of telegraphic wires, whilst it is not readily propagated through a space of the thousandth part of an inch of air. Impulses are readily transmitted by movements through the air of all other kinds of matter. Whence, then, arises the peculiar resistance of the air to the movement of electric matter, and why is it confined to the surface of metallic wires through an extent of a hundred miles, rather than to overleap a minute portion of space occupied by air?

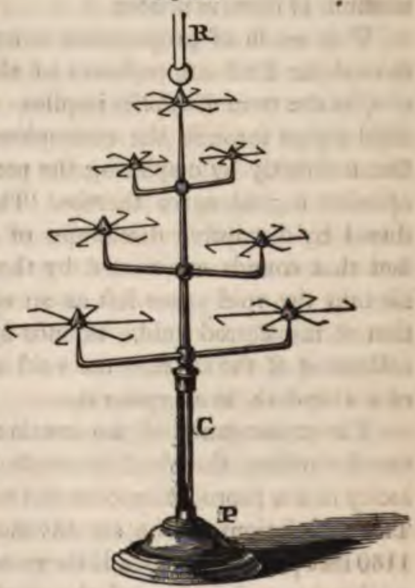
This very remarkable phenomenon appears to be due to the difficulty of establishing a determinate fixed polarization among the molecules of freely moveable atoms of air and gases. Instead of becoming regularly polarized in a continuous series, they readily yield to the first impulse propagated by electro-dynamic action, and are reciprocally urged to separate from each other, like the two freely movable pith balls of electroscopes. Instead, therefore, of propagating electro-dynamic action by the polarization of fixed arrangements of lines of atoms in consecutive series, the instantaneous separation of them is effected. Thus they react mechanically against the action propagated through the medium of electric matter from the excited body. The electro-dynamic impulses appear, therefore, to be expended in imparting actual movements to the molecules of fluid air, instead of propagating polarizations through a series of them.

That this result actually takes place admits of illustration by causing the smoke of an extinguished candle to rise up in front of the point of a wire attached to the conductor of an excited electrical machine. A rapid separation of the particles of the air from the vicinity of the point takes place in a continuous breeze or *aura*, as it is termed, as rendered visible by the movement of the smoke.

This phenomenon admits of the most perfect test by the application of the laws of mechanical science establishing that action and reaction are equal and in opposite directions. If the particles of air adjacent to the point of the wire be urged to move therefrom, there must be an equal and opposite reaction upon the point of the wire itself, causing it to recoil like a cannon discharging a ball.

This fact is experimentally tested by balancing a wire connected with the excited conductor of an electrical machine, on a pivot like a compass needle, with its extreme ends bended at right angles, as shown in the annexed wood-cut.

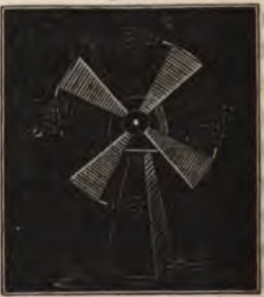
Fig. 102.



The wires, sustained on a stand, P, are insulated by the glass pillar, C, and connected with the excited conductor of an electrical machine by the rod, R. From each of the recurved points, the particles of air are simultaneously repelled, and the equal reaction upon the points produces a rapid revolving movement of the series of little frames, imparting to this machine an exceedingly interesting appearance, being operated directly by electro-motive power.

The current of air is also sufficient to propel light paper sails affixed to the arms of a wire frame, similar to the floats of a water-wheel. A model of a little mill wheel was arranged by Mr. Ferguson, to be operated by electrical agency.

Fig. 103.



To surprise playmates with the phenomenon of a windmill revolving without any apparent breeze, more than forty years ago I constructed a little machine to be operated by the reaction developed between the particles of air and wire points by electricity, as represented in the wood-cut.

These experiments demonstrate conclusively that the particles of aeriform fluids do not become polarized, like particles of iron filings, with similarly directed circuits of electric currents about their axes, and attracted reciprocally by an excited body; on the contrary, they are urged therefrom. Hence it is manifest, that when a mechanical action is propagated through the medium of the electric matter diffused throughout a mass of solid, readily polarizable material atoms, it is not reacted upon and resisted, as it is by aeriform masses, which require to be actually displaced and moved out of the way of the progressive impulses propagated through the medium of electric matter.

This mode of propagation is manifestly effected by *breaking through* the fluid atmospheres of all gaseous or aeriform particles, as the term *disruptive* implies. The propagation of mechanical action through the atmosphere appears therefore to be effected directly by displacing the particles in its progress, and by opening a void space therein. That this result is really produced by disruptive discharges of electricity is proved by the fact that sounds are caused by the collapsing of the displaced air into the void space left as an open path-way through a portion of transferred fluid. Sounds are similarly produced by the collapsing of the air into the void space produced by the action of a whip-lash, in *snapping* it.

The prolongation of the continuous sound of thunder-peals, or of "rolling thunder," is ascribable to a difference in the velocity of the propagation of sound and of electro-dynamic action. The undulations of the air advance with the velocity of only 1130 feet per second, or a little more than a mile in five seconds; whilst the undulations of the electric medium are propagated about a million of miles in the same period. The electro-dynamic action of a flash of lightning is propagated to the electroscopic nerves of the eye, in the modified form of light, almost simultaneously from the remotest and from the nearest point of its transit through a mile in extent of the atmosphere. But the mechanical action of the undulating wave of the air reaches the ear only at the expiration of five seconds after the perception of the flash. Consequently when a discharge of lightning takes place through the atmosphere from a cloud one mile high, above the observer, to the earth near his side, the flash and commencement of the sound of the thunder are simultaneously perceived. But the sound will continue to arrive at the tympanum of the ear for five seconds continuously, thus producing a prolongation of the action on the nerves of the ear during this period.

The displacement of the air, to produce a vacuum, requires a powerful mechanical action, as is well known to every scholar who has worked an air pump. The air must therefore oppose a very considerable resistance to a disruptive discharge of electricity. A cannon ball is arrested thereby in a few seconds of time.

These considerations afford us the means of calculating the comparative extent of the resistance of the air to the passage of a portion of electric matter, and to that of a cannon ball.

The resistance of the air is found to increase nearly in the ratio of the squares of the increased velocities. Taking the velocity of a cannon ball to be $\frac{1}{4}$ of a mile per second, and that of lightning to be at the estimated speed of light, or 200,000 miles per second, and calculating the increase of resistance to be in the above stated ratio, the resistance of the atmosphere to the disruptive discharge of electric matter through the air must exceed that opposed to the movement of the matter of a ball discharged from a cannon, in the ratio of 160,000,000,000 to 1. This intense resistance or reaction of the air affords a sufficient mechanical reason for accounting for the fact, that an impulse of mechanical force may be propagated through the medium of the electric matter existing in connection with the grouping of atoms of telegraphic conducting wires a hundred miles, in preference to leaping across $\frac{1}{10}$ of an inch of atmospheric air.

That the air in contact with conducting wires serves to impede also the propagation of disruptive action over their surfaces, is proved by an experiment made by Mr. Harris. Fine wires, which become red-hot when employed to propagate violent discharges from Leyden jars in the open air, ceased to become red-hot when arranged beneath a glass vessel exhausted of air. And when galvanic batteries are substituted in place of the Leyden jars in the preceding experiment, there appears to be very little difference in the result. This fact demonstrates the remarkable difference between the propagation of mechanical action through the medium of electric matter, by a disruptive discharge, and by electro-polarization of a series of consecutive atoms. The latter mode of propagation is not sensibly affected by the presence of atmospheric air, whilst the former is essentially obstructed, or rather confined thereby to the surfaces of conducting bodies.

On making contact of the circuit of a galvanic battery, and on breaking contact, there is induced a sudden displacement of the electric matter existing in connection with the conducting wire, and a sudden refluent recoiling surge thereof, as has just been described, which is equivalent to a disruptive discharge of a Leyden jar.

Void space serves to allow great facility for the propagation of disruptive discharges, as has been recapitulated of the electric flashes of the aurora borealis, and of the lambent flashes through void space, as illustrated by the figure at page 60. In void space there can be no matter to be acted upon, and to oppose reaction, or resistance, excepting the electric matter itself, which pervades all otherwise unoccupied space. By taking this fact into consideration, we are enabled to explain some of the most remarkable phenomena of the disruptive discharges of lightning from thunder-clouds.

Explanation of the Phenomenon of Lightning.

The sudden polarization of the atoms of the atmospheric ai in the line of the disruptive discharge of a flash of lightning, induces their instantaneous separation, and the consequent opening of a continuous line of void space between the clouds, and the earth. This separation of the atoms of the air causes the doors and windows of houses struck by lightning to be burst outwards as I have had occasion to notice.

On the sudden opening of a line of void space by a disruptive discharge of lightning, the resisting medium of intervening air is removed, and a ready pathway is offered for the propagation of electro-dynamic action between all portions of cloud, and the earth. This line of void space serves as a conducting wire suspended in the sky; toward which the minor disruptive discharges from different parts of a cloud converge in brilliant corruscations, like the confluent branches of rivers. This phenomenon of the reciprocal convergency or attraction of similarly moving electric discharges has been illustrated at page 218, by figures 18 and 19.

The approach of every minor lateral discharge toward the main discharge, induces the latter also to deviate from a straight line, and to exhibit the peculiar forked junctions, from which this form of disruptive discharge has received the popular name of "Forked Lightning."

When these accessions of collateral currents are numerous, they unite with the main disruptive discharge by such frequent reciprocal deviations from a straight line, as to induce the zigzag directions, so commonly observable in the exhibition of the sublime phenomena of a thunder-storm. These numerous forked junctions resemble the glittering links of a golden chain, suspended in the sky from the underside of a dark thunder-cloud. Hence, the term "Chain Lightning" has been popularly introduced to denote this peculiar phenomenon.

Functions of Pointed Bodies and Sharp Edges in promoting Electric Action.

When pointed wires are employed to propagate electro-dynamic action, it has been previously stated that the polarized atoms of air become urged therefrom in a continuous succession, constituting a breeze, or *aura*. The electro-dynamic action is thus silently transmitted, by imparting an actual momentum to the air and to other bodies exposed thereto. When globular bodies or flat surfaces are presented to the air, the disruptive discharge does not thus go on continuously; but accumulates in intermittent sparks. The former mode of propagation is continuous and silent;—the latter intermittent and noisy.

This difference is traceable to the fact, that by reducing the form of a conductor to a sharp point, the intensity of the force becomes concentrated; whilst the intensity of the resistance to polarization of the adjacent atoms of air becomes correspondingly diminished.

Supposing the flat surface of the area of a square inch to be compared with that of the point of a fine sewing needle, it admits of calculation that 10,000 of such points may be comprised within this area. If the intensity of the electro-dynamic action be augmented, and the resistance be correspoudingly diminished in an equal ratio, by the diminution of the number of atoms of air opposed thereto, the result may be estimated by multiplying this increased intensity by the diminished resistance (10,000 ×

10,000=100,000,000), showing it to be as one to one hundred million.

This theoretical calculation leads us to appreciate the advantage of the use of pointed wires attached to the main conductors of electrical machines, approximated to the revolving glass plate; and to comprehend why the same arrangement of pointed wires on the opposite ends of the main conductor would propagate electro-polarization to the atoms of surrounding air, as fast as it receives electro-polarization from the atoms of air intervening between the points and surface of the revolving glass plate of the machine.

As acute points are thus demonstrated to perform such important functions in propagating electro-dynamic action in the operation of electrical machines, by polarizing the atmospheric air, and by receiving reactions therefrom, we are furnished with a clue to unravel the mystery of the abundant employment of sharp thorny points in the mechanisms of vegetable bodies.

In describing vegetable organic formations, it has been demonstrated that they all constitute mechanisms systematically devised for receiving and propagating mechanical action through the medium of electric matter; and in describing the excitation of atmospheric electricity, it has been recapitulated that every flash of lightning propagates mechanical action to all bodies within a distance of scores of miles therefrom. It follows from these facts, combined with the preceding calculations of the functions of pointed conductors in determining the direction of the propagation of electrical machines, that the acute thorns and bristly spires of down, with which the branches, leaves, fruits, seed vessels, &c., of innumerable kinds of plants, are profusely provided, must exert an important electro-dynamic influence in determining the functions of vegetable organizations. It may be commonly noticed, that plants growing on arid soils, and furnished with the shortest roots, such as the various species of the Cacti, are the most abundantly provided with thorns.

The perfect acuteness of the points of natural thorns, when compared with the most perfectly acute points which human art can impart to steel needles, is wonderfully displayed by the microscope. And there is such an extensive system in this arrangement of thorny points in the mechanisms of vegetable bodies, even to those of the serrated edges of the spires of grasses, that the most skeptical must admit them to subserve some important design in the mechanics of nature.

These investigations lead to the consideration of the artificial functions of sharp-pointed and sharp-edged implements, commonly used by mechanics in puncturing and cutting wood, metals, &c. The philosophy of the selection of steel for sharp-pointed and sharp-edged cutting implements, is also involved in this inquiry, as founded on strictly scientific electro-dynamic principles.

To impart to atoms of iron the property of a masterly influence in overpowering the cohesion of nearly all kinds of hard substances, precisely the same preliminary processes of an artificial excitation are resorted to as are employed in imparting to the same iron the masterly electro-dynamic influence of permanent magnetic forces. The atoms of iron are first reduced from their natural polarized condition of an ore, to the constrained polarized condition of a smelted metal, as has been previously recapitulated. It is then further subjected to electro-dynamic excitation by a long process of exposure at a high temperature in contact with organic charcoal in an air-tight box. After this second excitation, it is subjected to a third process of electro-dynamic excitation in contact with the same organic fuel in a forge. In this last stage of extreme electro-dynamic excitation, the metal is withdrawn, and suddenly plunged into cold water, as if instantaneously to arrest and fix the constrained polarizations of the atoms.

After being subjected to these thrice-repeated excitations, the combined groupings of atoms of iron and carbon are recognized by the popular name of "tempered steel;" which is iron reduced to a highly constrained artificial electro-polarized state, by means of the combustion of fuel originating from solar influence on the mechanisms of the organs of plants, as has been reiterated in the preceding pages.

In this highly constrained electro-static condition, a blow of a hammer on a bar of this tempered steel whilst held in a sloping direction pointing toward the pole of the earth, or the subjection of it to the influence of an electric current, as described at page 247, figure 42, will impart to it permanent dynamic powers, recognized as magnetic.

The powerful electro-mechanical action propagated to bodies by moving near them these tempered steel magnets, has been recapitulated in treating of magneto-electricity. The most refractory substances yield like wax before a flame, when exposed to the electro-mechanical action propagated from bars of tempered and excited steel, used in powerful magneto-electrical machines. The cohesion of the atoms of a bar of solid silver, copper, and other metals, is overpowered at one point of the electro-dynamic circuit, and re-established at another in crystalline beauty and solidity.

With these analogies before us, can we longer deem it a matter of wonder, that this same tempered steel, which by its mere movement near other matter, is capable of simultaneously counteracting and re-establishing the cohesion of the atoms of such bodies, should be endued with the property of overpowering the cohesion of the parts of solid bodies, when its electro-dynamic powers are rendered intensely concentrated at the acute points or sharp edges of cutting implements, and in this state brought into contact with groupings of atoms cohering in solid bodies?

Indeed, the identical tempered steel chisels which have been employed successfully in turning off chips from refractory metals, may be subsequently employed as magnets in a magneto-electric machine, to restore to the severed particles their orignal crystalline grouping, by the present well-known process of electro-metallurgy. And the same mechanical power of the steam-engine, which is employed to operate the turning-lathe to cut off chips from a bar of metal, may also be employed to turn this magneto-electric machine, to reinstate them in their restored condition of cohesion in a solid mass.

When the keen edge of a razor is drawn over the selvedge of a piece of cloth distended to separate the severed parts from before the advancing blade, so as to oppose no resistance thereto, the phenomenon of cohesion yields as if by a magic touch to the trenchant blade.

That the cohesion or hardness of tempered steel is a contingent property, and not an inherent one, is demonstrable by referring to the experiment of cutting in two a cast-steel file, or a thick cast-steel saw-plate, with the smooth edge of a thin revolving disc of soft sheet-iron, as illustrated at page 310, figure

67. The rapid movement of the sheet-iron near the hardened steel file excites a reversed polarization of its component atoms, which then yield readily before the advancing edge of the soft iron. Indeed the rapid movement of the soft iron serves to propagate an overpowering electro-dynamic action to the steel at rest, equal to that which the steel in motion imparts to the iron on reversing their relative conditions. The action and reaction are equal between these two substances reciprocally in this case as in all others.

In using a razor, it is a common practice to dip it in warm water, to increase its trenchant powers. If there be any advantage derivable from this process, it may be ascribed to the induction of thermo-electric excitation.

In tracing out the valuable properties of steel for the purpose of cutting implements in the useful arts, the preceding facts indicate the originating source to be the electro-dynamic action of the sun on the organs of plants, through the modified groupings of atoms into fuel. The action is the more intense as the points or edges are reduced to the most acute forms, as has been recapitulated.

On Averting Disruptive Discharges of Lightning from Buildings.

The various expedients devised for the protection of buildings, and of the occupants of them, from injury by disruptive discharges of lightning, are all founded on the principle of providing some more readily polarizable body than the materials employed by masons and carpenters in the construction of edifices. When the materials employed in construction are readily polarizable, as where the roofs of buildings are covered with metal, with ample metallic water conductors descending to the ground and connected with metallic pipes extended beneath the moist earth, these arrangements afford a more ready pathway of polarizable atoms for the propagation of violent mechanical action through the medium of electric matter, than the bodies of the occupants living beneath such a roof. And so, also, in the construction of steamboats, so much readily polarizable metal is employed in the smoke-pipes, beams, piston-rods, and iron braces, that there is no case on record where a passenger on board of a steamboat has been injured by lightning.

The connection of the series of readily polarizable atoms of metallic conductors with the moist earth is an essential requisite in the arrangement of lightning-rods; for these rods do not propagate the disruptive discharges, unless the system of their polarizations be extended to the neutralizing reaction of the polarized matter of the moist earth.

It is not always sufficient to ensure the safety of buildings to employ a single pointed rod at the central apex of the roof; for the disruptive discharges of lightning are not always in a vertical direction. I have noticed instances where the courses of disruptive discharges of lightning have taken a sloping direction, at an angle of nearly 45° with the earth's surface. This fact was demonstrated by the mutilation of the small twigs and branches of forest trees in oblique lines towards the main trunks. The massy trunk of a walnut tree, seventy feet in height, I have seen completely split open at the height of ten or twelve feet from the ground, when the whole top remained uninjured. The sides of houses may sometimes be similarly struck by lightning.

In the preceding case it is manifest that the height, however great, of a single lightning-rod, can afford no certain protection; and hence no rule can be given for regulating the heights of the rods. For this reason the most perfect arrangement is to train the conductors over the pinnacles, and even along the eaves of a roof, with vertical points distributed at intervals, as is now commonly practised, and descending rods at the four corners.

A common bell-wire has been often found to conduct very destructive discharges of lightning from one part of a dwelling-house to another; and even a nail in a partition often serves to determine the direction of the action. A fine wire may therefore serve to insure the safety of the inmates of a dwelling, although it may be melted and destroyed by the discharge. The size of the metallic conducting-rods is not therefore so important as the multiplication of them. A copper wire of $\frac{1}{4}$th of an inch diameter, or an iron rod $\frac{3}{8}$th of an inch square, may be relied upon as of sufficiently large size.

It has been previously stated that the passage of electricity near any body serves to disturb the natural state of rest of the electricity existing in connection therewith. Consequently it may be calculated upon that the inmates of every building will be slightly shocked by a discharge of lightning, even when no trace of action may be discoverable on the conducting-rods that serve to transmit it.

In the construction of powder magazines, care must be taken that no metal be in contact with the inflammable material, to induce lateral discharges that may ignite it.

On Averting Disruptive Discharges of Lightning from Vessels.

The disruptive action of lightning upon vessels at sea has been more dreaded, than upon buildings on the land; as there is no secure retreat in the former case from the disastrous conflagration which frequently ensues.

When a portion of the mast and spars are splintered by lightning, the damage admits of being sufficiently repaired, to enable the crew to reach their port of destination. But when the disruptive discharge passes beneath the deck among the combustible materials of a cargo, they commonly become ignited. The conflagration becomes extended in every crevice between the packages and bales, where it is impossible to extinguish it, and where it continues smouldering until the heated deck is finally burnt through. The mariners are then compelled to retreat from amid wreaths of flame and smothering smoke to their open boats, with the uncertain chances of gaining some distant shore, or of being overtaken by some passing vessel. For these reasons our present subject is of vital importance to mariners.

In the arrangement of conductors on vessels, large wires or chains are usually extended from the tops of the masts to the water. These are movable, and are attached to the shrouds. As they are sometimes annoyingly in the way of the sailor, it has not unfrequently happened that vessels have been destroyed by lightning, whilst the lightning-rods are packed away in the store-room.

To obviate all objections to the general use of lightning-rods on shipboard, the expedient has been resorted to of affixing in a slight groove in the masts, a flat plate of copper, about ⅛th of an inch thick, of ribbon form, trained over the caps, the connection being maintained by similar plates affixed to grooves in the topmasts. From the sides of the masts, similar copper plates are trained along the under side of the deck, to the principal bolts inserted through the timbers of the sides, to form an unbroken communication with the external coppered bottom of the vessel.

A sufficient conductor to secure vessels against destruction by fire, admits of being arranged at so small a cost beneath the decks, that it appears to be an inexcusable neglect in every naval architect to omit it. As the disruptive discharges commonly descend the masts and pass through the decks, it is only necessary to nail strips of the sheathing copper, always left in coppering the bottoms of ships, against the mast under deck, taking care to arrange them so that packages of cotton or other combustible materials will not be in contact therewith. By connecting each strip of copper with one of the copper bolts passing through the kelson to the external copper, the conduction of a disruptive discharge will be complete. Few cases occur, in which this simple and cheap precaution would not prove sufficient to save a vessel from combustion by lightning.

On the Velocity of the Propagation of Mechanical Action through the Medium of Electric Matter.

Great discrepancies occur in the estimates of the velocity of the propagation of electro-dynamic action. Mr. Wheatstone has calculated this velocity to be at the rate of 288,000 miles in one second. Wollaston has estimated it to correspond with that of the light from the sun, or about 200,000 miles in one second.

Recent experiments of the propagation of mechanical action through the medium of the electro-polarization of telegraphic wires, have given practical results of a far less rate of velocity. In France, experiments made by Fizeau and Gounelle, have led them to suppose the velocity to be about 60,000 miles per second.

The velocity of the propagation of electro-dynamic action by the galvanic current, through telegraphic wires, has been found by the result of experiments made between a station in Cambridge, Mass., New-York, and Philadelphia, to be 18,700 miles in one second.

Professor Mitchell gives a result of 28,524 miles per second, as verified by experimental trials made by him over circuits 607 miles long.

In the very elaborate Report made by Mr. Gould, of a course of experimental investigations undertaken by him in accordance with instructions of Mr. Sears Walker, from the Department of the U. S. Coast Survey, it is stated that the wave of electro-dynamic action is propagated through telegraphic wires with the velocity of about 15,000 miles per second.

In making these experiments, the apparatus of a contact breaker connected with a clock pendulum was employed. There may be a question whether this intermittent mode of testing the velocity of the propagation may not give results differing from a regular continuous propagation of electro-dynamic action; for considering electric matter to be an elastic fluid ether, a series of alternating oscillations must follow each other. To use the words of Professor Henry, "In the discharge of a jar, all the phenomena indicate a principal action in one direction, and a series of reflex actions backwards and forwards, each more feeble than the preceding, until the equilibrium is restored."

The regular propagation of the electric action may thus be essentially interfered with by these recoiling electric surges, and a consequent irregularity of the results may be expected, such as appears thus far to have marked the progress of all these experimental investigations upon the velocity of the propagation of electric action.

The rapid velocity of the transmission of impulses of mechanical force has been rendered admirably available in determining the longitude of places on the earth's surface with almost perfect precision, by indicating, simultaneously, the instant of time denoted by well-regulated time-keepers at the several distant places, of the transit or occultation of the heavenly bodies.

On the Direct Mechanical Impulses Propagated by Electric Matter in Motion, or Momentum of Electricity.

In connection with the subject of the disruptive discharges of electric matter through the atmosphere, and through conducting bodies, with the extreme velocity which has been demonstrated, an idea of a momentum, like that of a rifle-ball, may be entertained. But it is difficult to conceive that any thing of so subtle a nature as to be deemed "imponderable," can be a subject of calculation as capable of propagating mechanical action by its momentum; for considerations of *weight*, as well as of *velocity*, are involved in calculations of momentum. Although the electric matter may be movable with extreme velocity, as an offset to its extreme *levity*, yet the laws of mechanical philosophy demonstrate that movements of atoms, rather than of masses, must be produced thereby.

The following calculations will serve to show, that although a disruptive discharge of electric matter might carry with it, in its rapid movements, a force of momentum, yet it is adapted rather to act on the electric matter surrounding the atoms of a mass, than on the mass. And that when the atmospheric air, or portions of rocks, trees, and other bodies, are shivered or displaced by lightning, that the mechanical action is not propagated directly to the mass of matter, but to the electric matter existing in connection therewith, inducing opposite polarizations of the atoms; and consequent reciprocal repulsions.

If the cohesion of the most solid bodies be due to the polarization of the component atoms, as we have supposed, and if the polarization of the atoms be reversed by disruptive discharges, or by the silent propagation of electro-dynamic action, then we may look to this counteraction of the very cause of cohesion, as the electro-dynamic effect produced by such discharges; and not to a mechanical action of momentum applied to move forward before it a solid mass of atoms.

Taking the uniform resistance of the natural forces of "cohesion," and of "gravitation," as standard measures of mechanical action, the following results I find demonstrable:

1st. By increasing the velocity of matter in motion, as for instance in a ten-fold ratio, its absolute momentum is increased in the same ratio, or as the mass multiplied into the increased velocity.

2d. By means of this increased velocity a tenfold augmented momentum is expended in $\frac{1}{10}$th of the time, in overcoming every kind of resistance, like that of cohesion, or gravitation, uniformly reacting during every successive instant.

Thus, a tenfold momentum is brought to bear on only $\frac{1}{10}$th of the former resistance. The effect threby produced is calculated by squaring the increased velocity ($10 \times 10 = 100$). Consequently an hundred-fold mechanical effect is produced in overcoming the constant resistance of Cohesion and of Gravitation. Hence, by this standard measure of mechanical forces, a rule has been adopted in the science of mechanics, that "the forces of moving bodies are increased in the ratio of the squares of the increased velocities."

But when the *propagation or reproduction of motion* in the bodies struck by an impinging body is taken as a standard measure of the mechanical impulses imparted, then another rule is to be adopted, which is simply in the ratio of "the mass multiplied into the increased velocity." A tenfold increase of motion in a body produces only a tenfold effect of increased motion of the body impinged upon.

By applying this scientific rule of calculation to the computation of the mechanical effects producible by augmenting the motion of matter from the velocity of $\frac{1}{4}$th of a mile in a second, being that of a rifle ball, to a velocity of 200,000 miles per second, being the supposed velocity of motion of electric matter, we have the following increase of mechanical power in overcoming the resistance of the COHESION of solid bodies by means of augmenting the movement of matter from the velocity of a rifle ball to that of lightning—

$$200{,}000 \times 200{,}000 = 40{,}000{,}000{,}000$$

$$\cdot25 \times 25 = \quad . \quad . \quad . \quad 6\cdot25$$

the increase is in the ratio of 40,000,000,000 to 6·25, or as 6,400,000,000 to 1.

When it is considered that with the comparatively slow velocity of the movement of a rifle ball, a sheet of window glass may be perforated, whilst balanced on its edge, without scarcely disturbing its position; that a door on its hinges is not moved at all by the transit of the rifle ball which shivers from it large splinters of the wood; and that even a portion of the metal of a copper coin, set up on its edge, may be clipped off by a rifle ball, as I have experimentally tested, without driving the coin before it, —it would be perfectly unphilosophical to suppose that electric matter, moving with 640,000,000,000 fold the velocity of a rifle ball can impart any perceptible movement to a mass of matter at rest, against which it may be caused to impinge. The electric matter might dissipate into impalpable dust the atoms of a portion of a solid mass without stirring the remainder of it.

When a sheet of glass is perforated by the electric spark, it is not moved. A clean round hole is commonly made, well defined on the side where it enters, and splintered off from the edges of the aperture on the opposite side.

These illustrations demonstrate that electric momentum cannot move solid bodies; and inasmuch as this subtile matter pervades the pores of all solid bodies, that it can only affect the states of motion and rest of terrestrial matter by affecting each individual atom of the mass.

This fact is beautifully confirmed in the experiment of employing the needle of a galvanoscope to test the action of the discharge of a Leyden battery. So sudden is the electric action, that the needle remains motionless; whilst the slightest continuous or prolonged excitation will cause it to swing round on its point, as may be also effected by using the imperfect conductor of a thread wetted with salt water, to prolong the period of the discharge of the battery.

Thus it is demonstrable, that in imparting mechanical impulses by electric matter in motion, *time* is to be taken into account, as an element in calculating the practical propagation of electro-dynamic impulses to masses of matter; we hence arrive at the conclusion that with the velocity of movement of electric matter, it can only affect the mass by affecting every individual atom of which the mass is composed.

The experiment of employing electric matter in discharges from Leyden jars for the purpose of perforating cards, sheets of glass, &c., and of driving before them pith balls resting between two pieces of sealing-wax, have been often adduced as tests of the development of the force of momentum of electricity.

These facts, from an attentive scrutiny of the circumstances attending the phenomena, appear to be ascribable to other causes than the absolute momentum of electric matter. For it admits of demonstration, that the presence of intense electric excitation among atoms of all compound substances, and particularly of organic formations in their constrained static condition, tends to decompose them, and to reduce the component elements to their natural static condition of carbonic acid gas and water.

By causing the discharge of a Leyden jar to pass through a drop of water or of oil, arranged between two insulated points of wire forming the circuit of discharge in the cavity of a small mortar containing a pith ball above it, the ball is expelled therefrom, as if by gunpowder, from the sudden expansion of the liquid into vapor. And even the particles of atmospheric air are caused, by the electro-dynamic polarization, to occupy more space, and similarly to project the ball. This experiment illustrates the fact of the bursting outwards of the windows of a house and the shivering of trees struck by lightning.

These explanations will also account for the appearance of the aperture left on a card by the passage of an electric discharge. The fibres project outwards on both sides of the paper, as if oppositely moving electric currents simultaneously had passed through it.

The experiment is also frequently made of holding a wheel, with paper vanes or floats like those of a water-wheel, in front of a pointed wire affixed to the prime conductor of an excited electrical machine, in order to show by the revolving of the wheel, the momentum of the issuing jet of the electric current.

This phenomenon is not produced by the impulses of the jet of electric matter; but is simply the result of the separation of the particles of the air immediately contiguous to the points, as occurs in the experiment with the ringing of the electric bells, figure 20, page 205. The brass ball suspended between the bells is first attracted by the excited ball and then repelled therefrom against the adjacent unexcited bell, propagating thereto its own momentum—not that of the electric matter. The movement of material atoms in currents induced by electrical action may be most distinctly exhibited by means of oil of turpentine, as before noticed, in glass vessels. The polarized atoms may be seen circulating in opposite directions between the two points of reception and discharge. A smoking snuff of a candle held at the end of an insulating rod towards a charged conductor, will sometimes render perceptible, by the movements through the air of the volatile carbonaceous particles, two opposite moving streams of smoke, one passing in the direction *toward* the charged conductor, and the other passing in a directly opposite direction *from* the conductor. In the former case the particles become similarly polarized and attracted; and in the latter case, they become expelled to a distance by an opposite polarized action.

It is sufficient for us to know that particles of air in currents are successively repelled from the point of the wire in the preceding experiments, in order to calculate that the point of the wire must be repelled reciprocally therefrom, like a recoiling gun.

How much of this motive force may be due to the actual mechanical impulse imparted by the momentum of the electric matter, this experiment does not decide; for the action and reaction between the ponderable particles of the air and the excited point of the wire are sufficient to produce the mechanical effects witnessed.

Admitting, as Müller states, that "motion produced by the discharge of the electric fluid from points, corresponds entirely to the phenomena exhibited by the rotation of *Segner's* water-wheel," which operates by the reaction of jets of water issuing at right angles to the arms, this comparison conveys an idea of mechanical action and reaction, such as take place between the recoiling cannon and the projected ball; and as the mechanical impulse of the recoil is measured by the momentum imparted to the projectile, it follows as a consequence of the adoption of this principle, that the force of recoil of the arms of the revolving wire, page 403, fig. 102, will be the measure of the momentum of the issuing electric fluid. But as we have shown that a current of particles of air is impelled from the points of the wires, it is certain that a portion of the reaction is ascribable to this fact, and that only a portion of the reaction can be ascribable to the electro-dynamic impulses communicated from the reaction of the escaping current of electric matter. At all events, with the most delicate experiments I could make for producing reaction by discharge from pointed wires, in the space devoid of air beneath the bell glass connected with an air pump, no movements of the revolving wire frames were producible. Hence it appears that the reaction of the particles of air excited by electro-dynamic agency is the cause of the recoiling movements of the little fly-wheel exhibited by the wood-cut at page 403.

This fact of the inefficiency of electric matter in motion to propagate impulses by the mechanical action of MOMENTUM, are here particularly noticed for the purpose of demonstrating the necessity of looking to other causes than this for explaining the mode of action of the electro-motive power.

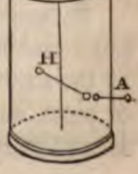
On the Intensity of the Propagation of Mechanical Action through the Medium of Electric Matter.

In referring to the historical account of the discovery of electro-motive power, it appears that Dr. Robison first demonstrated, so early as the year 1769, that the impulses of mechanical force of repulsion, developed by electrical agency between two approximated bodies, became diminished very nearly in the ratio of the increase of the squares of the distances. But it was not until about the year 1785, that the foundation of the science of electro-dynamics was established by Coulomb, who invented ingeniously-devised instruments for measuring the INTENSITY of electrical forces, and reduced them to rigid tests of mathematical calculations.

The experiments of Coulomb were directed to the exhibition of the electro-dynamic action that takes place between flat discs and round bodies, such as globes and cylinders, and other differently shaped bodies. The truthfulness of the experiments of this celebrated philosopher has recently been tested by Mr. Snow Harris.

The annexed figure represents one of the instruments invented by Coulomb for testing the intensity of the action of electric forces. It was denominated by him a TORSIONAL BALANCE.

Fig. 104.



This instrument is composed of an inverted glass jar, surmounted by a circular glass plate, with a hole in the centre. Through this hole a single fibre of a silk-worm's thread is inserted for the purpose of suspending a needle, H, which thread may be composed of any light substance, such as a filament of gumlac, a piece of silk thread, or a straw coated with sealing-wax. The ends of the needle are terminated by small pith balls, counterbalancing each other.

The upper end of the silk fibre is attached by a movable knob, having an index adapted to be set by the fingers against the marked degrees of a circle arranged beneath it. By turning the knob, the silk fibre and needle are both simultaneously turned, so as to bring the ball near another ball of metal, A, attached to the end of a wire passing through a hole drilled through the side of the glass jar. The intensity of the force of any excited body to be tested by this instrument is determined by bringing it into contact with the external knob of this wire, and by noticing the divergency of the needle from the internal knob.

The twisting or torsion of the silk fibre resists the divergency of the ball on the end of the needle. The comparative intensity is ascertained by regarding the index on the top of the jar, and noting the number of degrees which it requires to be turned, to force it back to its position opposite to the ball inserted at the side of the jar.

By using stiffer substances than a fibre of silk, such as fine wires, the resistance of torsion may be increased at pleasure, to gauge the extent of the electro-dynamic action.

The threads employed by Coulomb were more than two feet long.

The resistance of torsion in wires of the same kinds of metals, is found to become increased in the ratio of the squares of the increased diameters, and to be in the inverse ratio of the length of the wire. The comparative intensities of electrical action admit of very exact calculations by means of this instrument.

By the use of the Torsional balance, Coulomb ascertained that the same law which governs gravitating force governs electrical force, the intensity of the electro-mechanical impulses between approximated bodies being *inversely as the squares of their distances.*

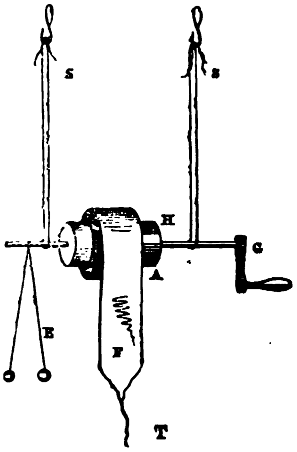
By means of this instrument Coulomb also discovered another important law in electro-dynamics, establishing that the intensity of the excitation of solid bodies is greatest at their remotest ends poles, and about their external surfaces; and that it diminishes diately beneath their surfaces, so as not to be discoverable.

By the test of the greater intensity of the electro-dynamic action developed at the ends or poles of long slender bodies, than at their middle parts, Coulomb judged that the electricity is accumulated in much greater quantities at the ends than at the middle parts of elongated bodies. He found by experiment with a cylindrical body, thirty inches long, and two inches in diameter, that the intensity of the electricity at the ends was, to its intensity at the middle, or at any part more than two inches from the extremity, as 2·3 to 1. The intensity at the centre of a circular plate he found to be only in the ratio of 1 to 2·9, as compared with that at the circumference.

When the excited body is drawn out to a point, a still more intense action is developed, the action before diffused over an extended area of the blunt end being thus concentrated to one focal spot. This phenomenon has been previously adverted to and explained, in treating of the influence of pointed conductors.

Coulomb assumed that the greater or less development of impulses of electro-mechanical force is identical with the greater or less accumulation of the electric fluid, as appears by his account of the laws of electric action, published in the Mémoires de l'Académie, in 1787. This idea is based on the presupposition that the particles of the electric fluid are endued with the self-originating power of exerting impulses of mechanical force; and that consequently, the greater the accumulation of particles, the greater must be the aggregate extent of development of electro-motive power.

Fig. 105.



To illustrate this supposition of Coulomb, the following experiment is adduced by Biot, to prove that in proportion to the accumulation of the electric atmosphere about the surfaces of bodies, the impulses of electro-mechanical force become increased.

Let A represent a cylinder, supported by a wire, H, inserted as an axis, and suspended by insulating silk strings, S S. This cylinder admits of being turned around by a crank, with a handle of glass, G. Let

F represent a sheet of tinfoil, or of other flexible metal, wound around the cylinder, and having a non-conducting silk thread, T, attached to the lower end of it, whereby this sheet may be drawn down and unwound from the cylinder. Upon the axis of the cylinder, communicating with the metallic sheet, a pair of pith ball electroscopes, E, are suspended by two linen threads.

On communicating a charge of electricity to this sheet of metal, whilst it is wound upon the cylinder, the electroscopic balls become divergent. On unwinding the sheet by pulling down the silk thread, T, the surface of the metal becomes enlarged, and the electricity is supposed to become diffused over a greater extent of surface. In proportion as the sheet is unrolled, the balls become less and less divergent; and in proportion as it is rolled up again, they become more divergent.

The fact of the increasing and waning divergency of the pith balls, keeping pace with the rolling up and unrolling of the sheet of metal, being admitted, the question occurs, What causes the divergency of the pith balls in this case, if it be not ascribable to the cause assigned by Coulomb?

Admitting that the reciprocal repulsion between the pith balls originates from the self-motive and self-directive "inherent" and "innate" powers of electric matter, and also from the matter of the pith balls, in accordance with popular theories, the deduction follows, that the greater the accumulation of this electrical atmosphere, the more intense must be the development of these self-originating and self-motive impulses. But if we are permitted to doubt the present popular theories of self-originating motive power inherent in matter, and confine ourselves strictly to the law of mechanical science, which establishes that matter cannot move itself, then we have to look to causes of motive power extraneous to the passive electric atmosphere environing the equally passive matter of the pith balls.

To the motive power applied to turn the crank-handle, G, of the machine for winding up the metallic sheet, we directly look, as to the immediate cause of the impulses propagated through the medium of electric matter to the pith balls. For unless this motive power were applied to wind up and to unwind the sheet of metal, there would be no variation in their divergency, if we except the gradual subsidence of their divergency from the propagation of the electrical excitation to surrounding matter. We have shown at page 282, figure 56, that by moving the excited conductor, A, gradually toward B, the pith balls suspended from B become more and more divergent; and that on withdrawing A from B, the same electroscopic pith balls become less divergent. This fact demonstrates the mechanical action to be propagated through the medium of electric matter between insulated bodies, by inducing the polarizations of their extreme ends, whilst the middle part of the conductor remains unaffected, as tested by the undisturbed drooping of the pith balls suspended therefrom. The greater and less divergency of the pith balls in this experiment, figure 105, is manifestly traceable as directly to the action of the fingers propagated through the medium of the crank-handle and intervening electric matter, as if they were immediately applied to separate the balls.

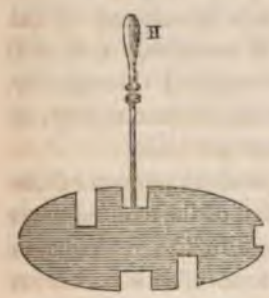
In the experiment of winding up the pendent portion of the metallic sheet, a relative elongation is effected of the excited parts of the same body, and a consequent change in the intensity of the polarization is induced, by the withdrawal of one part from another. The direction of the polarization is thus changed from the line of the axis, H, from one end of which the pith balls are suspended, to a new direction transverse thereto. This transference of the axis of polarization is equivalent to moving the pith balls from the end of an excited body to its middle part, where, according to Coulomb's own experiment, above recapitulated, he found the intensity of the electro-dynamic action to become reduced from 2·3 to 1.

This experiment has been here more particularly analyzed, because it has been commonly adduced as a conclusive proof, that excitation of electrical forces on the surfaces of bodies keeps pace with accumulation of electricity thereon; and that, consequently, the development of a greater or less extent of electrical forces must be due to the inherent self-motive power inseparable from the accumulation of a greater or lesser quantity of electricity. This experiment, more than any other, has tended to establish the belief that *quantity of electrical matter* and *intensity of electrical action are identical.*

That this idea is fallacious has been shown in treating of the voltameter, as a test of the quantity of electricity; and also in treating of the Excitation of Electricity, it has been shown that the intensity of the electro-dynamic action may be independent of the quantity of electric matter.

In the attempt to prove that no electric action, and that consequently no electric matter, exists within bodies, or beneath their surfaces, as above stated, Coulomb very ingeniously contrived the following experiment with a wire insulated by the glass handle, H, which he denominated a Proof Plane.

Fig. 106.



He bored holes half an inch in diameter, to the depths of $\frac{1}{16}$th to $\frac{5}{16}$ths of an inch, in various solid bodies, as represented by the sectional view given in the cut. He inserted therein the end of the piece of wire, carefully applying it to touch the bottom of the holes without touching the margins; and then he applied the end of the wire, or proof plane, to the ball, A, of his electrometer, figure 104. No indication of any electrical action was thereby discoverable; whereas the contact of the proof plane with any part of the exterior surface of the same solid body served to propagate strongly excited electric action to the torsional balance.

The fact that the internal parts of the groupings of atoms of solid bodies do not exhibit indications of electrical excitation, whilst the external parts are powerfully excited (as detected by the preceding experiment of Coulomb), corroborates the suggestion of the polarization of the internal atoms, which are represented by figure 46, at page 252. The oppositely directed propagation of the electro-dynamic action and reaction about the interior atoms, as indicated by the arrow-heads, must counterbalance each other, and produce necessarily, a neutralized electrostatic condition, as Coulomb's experiment practically demonstrates.

In corroboration of this supposition may also be adduced the experiment of Faraday, who constructed a metallic chamber large enough for him to enter with his electroscopes. This electrical chamber was insulated on glass supporters, in his lecture-room. Whilst sparks were vividly darting from the external sides of the excited chamber to adjacent bodies, not the least evidence of electrical excitation was indicated by any of the electroscopic instruments employed by him within the chamber.

The preceding phenomenon of electric quiescence, or cessation of discoverable electric action between the atoms constituting the interior parts of solid bodies, simply represents the electro-static condition of the groupings of atoms, which has been repeatedly referred to in the preceding pages. A similar electro-static condition takes place when the ends of the two insulated excited conductors are brought into contact with each other, as represented by figure 56, at page 282. The pith balls suspended from the conjoined sections, or middle part of the conductor, B, will manifest no signs of electrical excitation by their divergency, whilst in perfect contact; and will became instantaneously divergent when separated. The electro-polarization of the ends of the masses at sensible distances becomes reduced to a reciprocal molecular attraction between the individual atoms when they are brought within insensible distances of each other. The same phenomenon occurs when the two N and S poles of magnets are brought into contact. Electro-dynamic action is developed by the poles at insensible distances between the conjoined parts, and no further action, external to the surface, is discoverable by the test of the "magnetic" attraction of iron filings.

Although it might be assumed by this test of attracting iron filings, that the conjoined poles of two powerful magnets lose their magnetic powers, and that there is no longer any magnetic atmosphere equivalent in this case to the electric atmosphere, as tested by Coulomb's experiment, yet we know that a double intensity of the magnetic forces is exerted between the two conjoined poles. To test this fact, it is only necessary to attempt to pull the conjoined poles asunder; when it will be found that the insensible external forces are resolved into doubly intense molecular forces between the atoms brought into contact by the junction of the two ends. At the instant of overpowering the molecular action at insensible distances between the conjoined ends, by forcing asunder the conjoined poles, this molecular action becomes again resolved into magnetic action at sensible distances, and external to the surfaces of the magnetic bodies.

These considerations induce us to believe that Coulomb's experiment, above described, is not a proof that electric matter is distributed only over the surfaces of solid bodies, like a thicker or thinner atmosphere; but on the contrary, that it is only a proof of the fact of a resolution of electro-mechanical action between the external surfaces of approximated bodies into molecular polarization or action between the internal atoms at insensible distances.

INTENSITY OF ELECTRICAL EXCITATION REPRESENTS INTENSITY OF MECHANICAL ACTION.

The QUANTITY of electricity, it has just been shown, is commonly judged of by the extent of the mechanical effect of the separation of the pith balls, of gold leaves, of the movements of conducting wires and magnetic needles of galvanoscopes, of the movements of animal muscles, &c. In like manner the INTENSITY of electricity has been judged of by popular writers by observations of relative extents of the same mechanical effects.

As all mechanical effects are produced by mechanical action, it follows that all knowledge both of quantity and intensity of electricity is based on mechanical action:

The following proofs have been assumed by popular writers as standard tests of the relative intensity of electric excitation:

1. The power of turning on its pivot the compass needle of a galvanometer.
2. The power of imparting to fine wires a vibratory motion, constituting the phenomenon of heat, as has been previously detailed.
3. The power of separating the atoms of compound substances constituting the phenomenon of chemical decomposition.
4. The power to produce movements of animal muscles.
5. The power to propagate mechanical impulses to remote distances, as through telegraphic wires.

All these standard tests of the intensity of electrical excitation corroborate the general principle of the *Identity of Electrical* and *Mechanical Action*, which has been traced through every detail in the preceding pages. Intensity of electrical excitation, therefore, simply represents intensity of propagation of mechanical action through the medium of electric matter.

In treating of this subject, it may afford instruction to trace the remarkable difference of intensity developed by means of frictional electric machines and galvanic batteries. Comparative experiments have been made by Faraday to exhibit in contrast this remakable difference.

The minute galvanic apparatus employed by him consisted of the tips of two wires $\frac{1}{8}$th of an inch in diameter, the one of zinc and the other of platinum, arranged at a distance of $\frac{1}{3}$d of an inch apart. These two wires were plunged to the depth of $\frac{5}{8}$ths of an inch in a very weak acid, composed of one drop of oil of vitriol in four ounces of water. By this apparently trifling apparatus, as intensely powerful impulses of mechanical force were propagated in deflecting the needle of a galvanoscope during three seconds, as were propagated to deflect the same needle when the galvanoscope was connected with an electrical machine constructed of a glass plate 50 inches in diameter, subjected to the friction of two sets of rubbers during 30 revolutions. In addition, the electricity was accumulated on the surface of a battery of Leyden jars, and on a conductor with a metallic surface of 1422 square inches, so as to render the intensity of its action greater by accumulation.

The intensity of the excitation of this powerful electrical machine was sufficient to yield sparks, through the air, from 10 to 14 inches in length; yet the minute galvanic apparatus exceeded it in the power of deflecting the magnetic needle of the galvanoscope.

On the contrary, the largest galvanic batteries exert feeble powers in producing the divergency of the pith balls of electroscopes, which the minutest electrical machines will instantaneously produce. By the test of a voltameter, the largest electrical machines yet constructed do not serve to produce a sufficiently intense excitation readily to decompose water, which a minute galvanic apparatus will effect.

The accumulation of electricity on the plates of an excited galvanic battery cannot be sufficiently intense to produce the violent disruptive discharges and sparks, which are readily obtainable from the insulated prime conductor of an electrical machine, "because the two extreme plates are separated by a liquid, which is a good conductor of all charges except such as are of feeble intensity." It is probably to the superior insulation of the plates of the Dry Piles, which have been described as producing sparks, and the divergency of pith balls, that their superior intensity is ascribable.

By increasing the number of pairs of plates of a galvanic battery, the power of the apparatus, according to Professor Faraday, becomes proportionately exalted in "intensity," whilst the "quantity" of electricity in the current cannot be increased with the increase of the quantity of metal oxidized and dissolved at each new place of chemical action, in the numerous successive cells of the battery. He states that "a single pair of zinc and platina plates throw as much electricity into the form of a current by the oxidation of 32½ grains of zinc, as would be circulated by the same oxidation of a thousand times that quantity, or by that of nearly 5 pounds of zinc at the surface of 1000 pairs placed in regular battery order."

The preceding remarkable difference of intensity of mechanical action developed by means of frictional electrical machines and of galvanic batteries, appears to be ascribable to the difference of the electro-mechanical action between molecules and masses; the one developed at insensible distances between the atoms, and the other at sensible distances beyond the external limits of atoms. The one constitutes the polarization of atoms, and the other that of masses.

Our prescribed plan will not admit of pursuing farther these synthetical researches for tracing out the sources and modes of propagation of mechanical action through the medium of electric matter, which constitute modifications of natural motive power. Sufficient has been premised to render manifest the difficulties which embarrass this inquiry, involving so many subtile modes in which mechanical action is propagated through the medium of electric matter. It becomes an exceedingly laborious task for the limited powers of human perception patiently to trace them out, and to appreciate them duly.

It has been shown that the mechanical action originating from the sun is continuously propagated to terrestrial matter, and between portions of terrestrial matter successively, in the variously modified forms of heat, light, electricity, magnetic and chemical actions, cohesion, &c. By Protean changes from one static condition of groupings of atoms to another, constituting inorganic and organic formations, this electro-mechanical action becomes continuously and successively propagated by some one or other of the above recapitulated modes. At one time the propagation disappears, or apparently ceases to exhibit any discoverable developments, being counterbalanced in electro-static conditions until it becomes finally resolved into dynamic impulses. Patient labor is required to pursue and detect the modified forms in which the resultant mechanical impulses may be thus propagated through the medium of electric matter. This fact has been strikingly illustrated by the condensation in the atmosphere of a jet of steam from a steam-boiler. The detection of the propagation of electric sparks and currents from the hydro-electric machine (page 38), by polarizing the atoms of the surrounding air, is a discovery of a very recent date, although it constitutes the very basis of the motive power of the steam engine, and the most efficient source of motive power available by man. When the extent and nicety of these researches are considered, we may justly become impressed with an almost overwhelming idea of the prolonged vigilance and watchfulness requisite for duly appreciating the phenomena of the states of motion and rest of all terrestrial matter. The accomplishment of this task will require the persevering labors of men of future generations.

When these difficulties are appreciated, there will be no apology requisite for mistaken views, which fallible human intelligence may take, of the causes of the movement of matter by an agency so subtile as to elude direct observation, and to require recourse rather to reasonings from analogy, than to the direct perceptions of the senses.

In concluding this synthetical view, and before entering upon an analysis of the facts which have been detailed, it will be proper to present the opinions which have been advanced by intelligent philosophers in explanation of the facts and phenomena which have been recapitulated in the preceding pages.

As the mechanical tests of reciprocal movements of portions of matter *toward* and *from* each other, constituting the phenomena of ATTRACTION and REPULSION, are assumed to be the basis of the popular theories of electricity, it is manifest that in investigating the causes of these phenomena, we necessarily involve the consideration of these theories.

PROPAGATION OF MECHANICAL ACTION BETWEEN PORTIONS OF MATTER, IN THE FORM OF ATTRACTION AND REPULSION, AS TESTS OF THE POPULAR THEORIES OF ELECTRICITY.

The present popular theories of electric excitation are founded on observations of the movements of light bodies toward and from each other, constituting attraction and repulsion. These reciprocal movements of portions of matter have been illustrated by the figures of the electroscopic pith balls at page 201.

In using the tubes of glass and sticks of sealing-wax, which once constituted the only electrical apparatus employed for exciting electricity, it was noticed by Dufay, in Paris, that when one pair of pith ball electroscopes was excited by contact with the surface of the rubbed glass, and another pair by contact with the surface of sealing-wax, that the two pairs reciprocally attracted each other, although the two balls of each pair simultaneously repelled each other.

This was a new and surprising fact. It had never before been noticed, and required explanation. Dufay, as the discover, felt it incumbent on him to give a rational explanation of the remarkable phenomenon. This simple fact has given rise to more philosophical discussion, and speculative theories, than any other ever discovered by man.

To explain the facts of the movements of portions of matter toward and from each other under the preceding circumstances, Dufay supposed, that to produce the two opposite kinds of movements of the two pairs of pith balls, there must exist two different kinds of electric fluid. Hence his theory has been denominated the "TWO-FLUID THEORY."

THE TWO-FLUID THEORY OF ELECTRICITY.

Having first discovered the fact of the opposite and counteracting forces of the electricity excited from glass and from sealing-wax, Du Fay originally employed the terms VITREOUS and RESINOUS, as descriptive names of the two kinds of electric fluid, the one derived from, and inherent in, the *vitreous* matter of glass, and the other from the *resinous* matter of sealing-wax.

He reduced his "Two-Fluid Theory" to the following characteristic facts, to explain the preceding phenomena.

"A *repulsion* takes place between bodies charged with the same kind of electricity, and an *attraction* between bodies charged with the opposite kind."

"They are both equally subtile and elastic, universally diffused, and, therefore, present in all bodies, possessing the most perfect fluidity, each *highly repulsive* to its own particles, and as *highly attractive* to those of the opposite kind; these attractive and repulsive forces being exactly equal at the same distance, and both varying inversely as the square of the distance varies. Electric quiescence is said to take place, when the two fluids become combined and neutralized with each other; and electric excitation is the consequence of either fluid being in excess."

"Excitation is therefore the result of setting free from their combined state one kind or the other of electricity in excess."

Du Fay proposed, as a test of the kind of electricity excited in any body, to bring near it a piece of thread, the pith balls, or gold leaf of electroscopes, or any other freely movable bodies, after having previously excited them by contact with a piece of glass that has been subjected to friction. If the body thus excited by contact with the surface of rubbed glass be repelled by the excited body to which it may be approximated, this fact determines the electricity in each body to be the same, or *vitreous;* and if attracted, then it must be different, or *resinous.*

Since the days of DuFay this simple test has been resorted to as a standard mode of determining whether the kind of electricity, with which a body is excited, be *resinous*, or *vitreous.*

It is proper here to notice that the terms VITREOUS and RESINOUS, are not truthfully descriptive of the fact that these two oppositely-acting electrical forces are exclusively excitable from *vitreous* and *resinous* substances, as the derivation of these names might imply.

It was demonstrated by John Canton, in 1753, that at a single stroke of the same rubber, both vitreous and resinous electricities become developed on the surface of a glass tube, if one end thereof be rendered rough by grinding it with emery sprinkled on a sheet of lead; whilst the other end is left smooth with its natural polish. The smooth end renders manifest the vitreous electricity, and the roughened end the resinous electricity.

It has since been practically found, that the same piece of glass may be made to develop either kind of electrical force at pleasure, accordingly as various kinds of substances are employed as *rubbers*. For instance, if the surface of a piece of glass be rubbed by the dry, warm fur of a cat, the peculiar force denominated "*resinous* electricity" becomes developed; and, on the contrary, the "*vitreous*" forces become developed from a piece of sealing-wax, when rubbed with dry, coarse paper.

It is experimentally demonstrable that merely a *difference of color*, producible by dying a piece of white silk ribbon to a black hue, will change the character of the electrical forces from vitreous to resinous; which may be readily effected by drawing it rapidly between the fingers.

By examining the *rubber*, as well as the body *rubbed*, it has been found that in every case where the vitreous force is developed in the body rubbed, that the opposite kind of resinous force is developed in the rubber; and that one kind of force cannot be excited without the simultaneous excitation of the other. There are found to be action and reaction in two opposite directions, as regularly as when a ball is put in motion by the discharge of a cannon. Mr. Du Fay had no other reason for assuming the existence of two distinct kinds of electric fluids than the preceding fact of the development of mechanical action in two opposite directions. To produce oppositely-directed impulses, he assumed that there must be two distinct or opposite kinds of electric fluids. He appears to have identified fluids and forces,—matter, and mechanical impulses propagated through the medium of matter.

SINGLE-FLUID, OR FRANKLINIAN THEORY OF ELECTRICITY.

The Two-Fluid Theory continued to be a generally adopted hypothesis for explaining the phenomenon of electric excitation, until Franklin and Dr. Watson, almost simultaneously, brought forward another hypothesis, denominated a "Single-Fluid Theory."

Since the publication of the Single-Fluid theory by Franklin, about the year 1750, the opinions of philosophers have been divided in the acceptance of them. But as both of these theories, with certain modifications, serve to afford consistant illustrations of all the phenomena of electro-dynamic action, they may be alike conventionally used for explaining systematically the facts of electrical science, notwithstanding both of them demand the concession of principles at variance with some of the fundamental laws of mechanical science. But for this reason both of these theories are entirely inadmissible in a treatise on mechanical science.

Most of the philosophers on the continent of Europe adopt the terms and ideas of the Two-Fluid theory in their writings. The Franklinian theory, Becquerel observes, "still has many advocates, although it does not continue to satisfy the requirements of scientific accuracy.

The following account of the single-fluid theory of electricity is extracted from Priestly's History of Electricity:—

"All the operations of electricity depend upon ONE FLUID, extremely subtile and elastic, dispersed through the pores of all bodies; by which the particles of it are as strongly attracted, as they are repelled by one another.

"When the equilibrium of this fluid in any body is not disturbed, that is, when there is in any body neither more nor less of it than its natural share, or than that quantity which it is capable of retaining by its own attraction, it does not discover itself to our senses by any effect. The action of the rubber upon the glass, &c., disturbs this equilibrium, occasioning a deficiency of the fluid in one place and a redundancy in the other.

"This equilibrium being forcibly disturbed, the mutual repulsion of the particles of the fluid is necessarily excited to restore it. If the two bodies be both of them overcharged, the electric atmospheres repel each other, and both the bodies recede from one another to places where the fluid is less dense. For, as there is supposed to be a mutual attraction between all bodies and the electric fluid, electrified bodies go along with their atmospheres. If both the bodies be exhausted of their natural share of this fluid, they are both attracted by the denser fluid, existing either in the atmosphere contiguous to them, or in other neighboring bodies; which occasions them still to recede from one another, as much as when they are overcharged.

"Lastly, if one of the bodies have an overplus of the fluid, and the other a deficiency of it, the equilibrium is restored with great violence, and all electrical appearances between them are more striking."

In the practical application of this Franklinian theory, the component atoms of the single electric fluid are supposed to have inherent powers to repel each other with a mechanical force diminishing in the inverse ratio of the squares of the distances, and to be attracted by all material atoms or bodies according to the same law. All the elementary atoms of matter in their unexcited or natural states are deemed to be combined to saturation with electricity, and thus neutralized.

Bodies having a *positive* excess of electricity, it is affirmed, repel each other, from the tendency of the self-diffusion of the electricity with which they are charged.

But unfortunately for the theory of Franklin, it is found experimentally that bodies *denied of their natural share of electricity*, or in *the negative* state, as it is termed, also repel one another with just as much force as the bodies charged with a *positive* excess of electricity.

It has therefore been deemed necessary by Æpinus and Cavendish, to amend the Franklinian theory, by adding an entirely new doctrine to it, to account for the last described phenomenon of repulsion between bodies considered as devoid of electricity. This new doctrine is no less than an assumption "that all ponderable bodies *naturally repel each other* with the same force, and according to the same law as the particles of electricity."

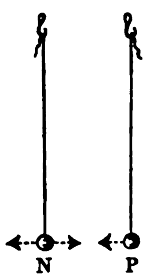
Thus the difficulty of accounting for the movements of negatively electric bodies is answered, by ascribing *innate* or *inherent repulsive forces* to *passive matter;* and the indifference to motion or passiveness of unexcited bodies, is also accounted for, by supposing that the *attractions* between the electricity naturally existing in connection with all matter, is counterbalanced by the "*natural repulsion*" between all such matter.

The reader will again observe here, that this supposition of a *natural repulsion* between atoms or masses of matter, is at direct variance with the law of the incapability of matter to move itself, and more particularly the law of the *reciprocal attraction* with, instead of *repulsion* of, all masses of matter, as established by the Newtonian principle of gravitation.

Mosotti, in his Treatise on the Forces which Regulate the Internal Constitution of Bodies, (see Taylor's Scientific Memoirs, page 469,) maintains that the "*natural repulsion* of the particles of matter for each other," adopted in explanation of the Franklinian theory, *is not in opposition* to the law of the universal *attraction* of gravitation, established by Newton; for he considers "that if the molecules of matter, surrounded by their (electrical) atmospheres, attract each other when at a greater, and repel each other when at a lesser distance, there must be between those two distances an intermediate point, at which molecules would be neither attracted nor repelled, but would remain in steady equilibrium," &c. P. M. Roget remarks, in his admirable Treatise on Electricity, "by supposing that the mutual repulsive action between the particles of matter is, by a very small quantity, less than that between the particles of the electric fluid, a small balance would be left in favor of the attraction of neutral bodies for one another, which might constitute the very force which operates under the name of gravitation."

Without this bold assumption of repulsion between bodies devoid of electricity, the *repulsion* that is found to take place between two *negatively* electrified bodies could not be accounted for, without attributing equal impulses of mechanical force to bodies *devoid* of electricity, or in a negative state, as to those charged with an excess of it or in a positive state, which would render this theory quite absurd. Even the admission of the above-stated amendment to the Franklinian theory will not save it (as will appear by reference to the following diagram), when it is attempted to apply it to explain the fact of the attr between a *negatively* and *positively* electric body. Let N a represent two balls suspended by insulatin threads, the one, N, being rendered *nega* and the other, P, *positively* electric. In a ance with the above described "mutual sion between ponderable bodies," the b should render manifest a repulsive ten toward P, as being another "*ponderable* and should recede therefrom; whilst at th time it should exert an attractive ter toward the excited body, P, ascribable "mutual attraction between all ponderable bodies and th tric fluid" that is contained in P.

Fig. 127.



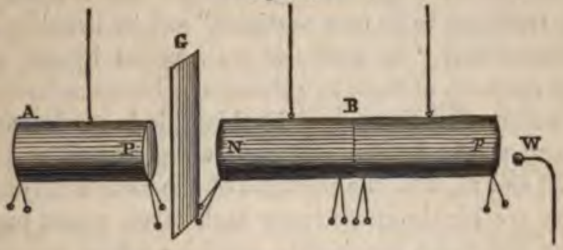
This attraction and repulsion being supposed to be according to the terms of this theory, the ball N should stationary between the counterbalancing action of the forces. This is not the fact; for there are found to be a an equal reciprocal mechanical action and reaction, den the term reciprocal "attraction," between these two b tested by their movements with equal relative velocities each other.

The affirmation that "the particles of electricity are at by all bodies," may be proved to be untrue by experim placing excited bodies in the void space beneath the b of an air-pump. All such bodies are found to part wit electricity in a vacuum; and two balls electrically excited repel each other at all in void space, where this theory lead us to expect the most powerful action. Mr. Thom serves, in his treatise on Heat and Electricity, "there d appear to exist any attraction between electricity and pon matter."

Finally, as observed by Dr. Turner, "with such additi theory of Franklin would virtually cease to be that of a fluid, and would still, I suspect, be less generally applicab the theory of Two Fluids."

The following experiment serves to show that the ap "*separation of the two electricities,*" is, in reality, nothin than an action of oppositely-directed forces; and that a taining this apparent separation in the two ends of a conductor, if the ends be suddenly swung asunder, a similar development of oppositely-directed forces becomes equally manifest in each of the ends of the separated conductor. This phenomenon has been previously referred to in treating of INDUCTIVE EXCITATION and POLARIZATION.

Fig. 108.



Let A represent a conducting body excited by contact with rubbed glass, and insulated by suspension from a silk cord; and N, *p*, two conjoined, unexcited conductors similarly suspended by two cords, by which they may be swung asunder at pleasure; and let G represent a sheet of glass interposed between P and N.

On approaching the excited conductor, P, near to the end of the unexcited conductor, N, even with the sheet of non-conducting glass, G, intervening, it is found that the pith ball electroscopes hung from each end of N, *p*, become divergent in proportion as the excited body is approached near it.

By the "two-fluid" theory it is supposed that the two electricities naturally existing in N, *p*, are decomposed and separated to the two ends. Now let the two halves of the conjoined conductor be dexterously separated by means of the suspending cords beyond the sphere of each other's influence. It might be supposed that by this management the two kinds of vitreous and resinous electricities would be secured in separately insulated conditions in the two disjoined halves; but so far is this from being the fact, it becomes immediately discoverable, that the electroscopic balls, which previously hung drooping from the centre of the conjoined conductor, becomes divergent when, at the ends or poles, the one with vitreous, and the other with opposite resinous forces; whilst at the centres of each there is exhibited again the same electro-static condition. However numerous may be these subdivisions, even when reduced to atomic proportions, still the same phenomena of oppositely-directed atomic forces become developed at the opposite ends or poles. Thus a principle of POLARIZATION becomes manifested for the government of the action of electric forces, which has the strongest analogy to magnetic polarization.

By Du Fay's theory, the vitreous electricity is affirmed to be "highly repulsive to its own particles," and by Franklin's theory it is affirmed that "the particles are repelled by one another." To carry out both of these two theories, it becomes further necessary to assume that there must be three kinds of electricity; for it has been shown by the experiment represented at page 220, figures 20 and 21, that the particles of the same kind of galvanic electricity are highly attractive to each other, whilst propagated in similar directions, and highly repulsive whilst propagated in opposite directions, the phenomena of attraction and repulsion being dependent simply on the direction of the electro-dynamic impulses.

In order to answer the question experimentally, are there really two kinds of electricity? Professor Faraday, with the zeal which has distinguished the career of this extraordinary man, instituted a course of "Experimental Researches."

He constructed a cubical apartment, 12 feet square, covered with a wire netting, under tinfoil, to render all parts of the surface a perfect conductor. He states, "I went into this cubical room, and lived in it; and using lighted candles, electrometers, and all other tests of electrical states, I could not find the least influence upon them, though all the time the outside of the cube was powerfully charged, and large sparks were darting off from every part of its outer surface. Every attempt to communicate to conductors, as well as to non-conductors, and to the air within this chamber bodily and absolutely, an independent charge of either kind of electricity, entirely failed."

Hence, Professor Faraday concluded it to be impossible to charge matter with either kind of electricity, exclusively, without the accompanying appearance of the other sort of electrical action in some form or other; and that there is never one kind of force or one fluid only. The numerous experiments which imply the possible separation of these two kinds of forces, as well as the expressions, which, being used daily, assume this to be the case, he supposes to be in contradiction with facts, the two forces being every where simultaneously developed, where electrical excitation exists. He affirms, "it appears to me to be as impossible to assume a current of *positive*, or a current of *negative* force alone, or of the two at once, with any predominance of the one over the other, as it is to give an absolute charge to matter." And, he continues, (Experimental Researches, 1163,) "In the long continued course of experimental inquiries, in which I have been engaged, this general result has pressed upon me constantly; namely, the necessity of admitting two forces or directions of force, combined with the impossibility of separating these two forces or electricities from each other.

Judging from facts alone, there is not as yet the slightest reason for considering the influence, which is present in what we call the electric current, as a compound, or complicated influence. It has never been resolved into simple or elementary influences."

The fact of "the impossibility of separating the two forces or fluids from each other," as above stated by Professor Faraday, has been anticipated and explained at page 258; where it has been shown that the two opposite forces, representing the two kinds of electricities, simply denote the mechanical action and reaction which must necessarily take place between electric matter, as well as between all grosser matter, in accordance with the laws of mechanical science.

It having been previously established that the propagation of mechanical impulses through the medium of electric matter constitutes electrical action, and that consequently mechanical action and electro-dynamic action are identical; and also that an impulse of mechanical force can be neither more nor less than an impulse of mechanical force, however originated or propagated: it follows as a necessary consequence, that electrical action must be governed by the established laws of mechanical science. No scientific mechanic could entertain the idea for a moment of the possibility of exerting an impulse of mechanical action without developing simultaneously an equal and oppositely directed mechanical reaction. He could not even anticipate the development of electrical action, without a simultaneously developed equal and oppositely directed reaction. It seems to be perfectly plain, that if a portion of electric matter be disturbed on the surface of a rubbed body, and put in motion in one direction about it, that an equal portion of the same subtile matter must be put in motion about the surface or about the atoms of the rubbing body, in an exactly opposite direction. The oppositely directed movements of bodies being adopted as the only known test of their oppositely directed electric impulses, as has been recapitulated, this standard test is adducible to demonstrate the truthfulness of this law of electric action and reaction. The "Two fluids" of Du Fay appear thus to represent simply the oppositely directed mechanical impulses of action and reaction.

These inconsistencies have produced a diversity of conflicting opinions in relation to the truthfulness of both of the present popular Theories of Electricity. In a series of "Objections to the theories, severally, of Franklin, Du Fay, and Ampère," Dr. Hare has published in Silliman's Journal, 1848, the outlines of an electrical theory. He considers that in order to dispense with the hypothesis of the existence of self-motive *repulsive* powers inherent in lifeless matter, it has been attempted to explain the phenomenon of electric repulsion, or the separation of electrically excited bodies, by ascribing it "to an attraction between the two remotest sides of such bodies and the atmospheric air contiguous thereto, which becomes oppositely electrified by *inductive excitation.*"

By adopting this supposition, the phenomenon of repulsion is resolved into a stronger attraction between the opposite sides of two similarly excited bodies and the adjacent air, than between the approximated sides of such bodies.

If this supposition were true, there should be a movement of the attracted particles of air toward the two remotest sides of two approximated excited bodies, such as does actually occur, *from* sharp-pointed bodies, to sustain the revolving movements described at page 403, figure 108. To sustain the continuous divergency of a pair of electroscopic pith balls on this principle, there should be a continuous perceptible current toward each ball, to afford a mechanical reaction precisely equal to the action. This is not a fact.

It is affirmed, in the words of the Two-Fluid theory, that "a repulsion takes place between bodies charged with the same kind of electricity, and an *attraction* between bodies charged with the opposite kinds,"—"each *highly repulsive* to its own particles, and as *highly* attractive to those of the opposite kind, their attractive and repulsive forces being exactly equal, &c." And in the terms of the Single-Fluid theory, it is in like manner affirmed, that the particles of electricity are as strongly repelled by one another as they are attracted by those of all grosser matter. The authors of both of these theories have thus ascribed the cause of the impulses producing the mechanical movements both of electric matter, and of all grosser matter, directly to the endowment of a power of self-movement, and of governing the direction of their movements.

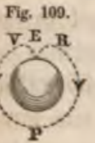
In treating of the phenomenon of the divergency of the pith balls of electroscopes, at page 257, the originating cause has been traced to a source external to terrestrial matter, and 95 millions of miles distant therefrom; thus leaving inviolate the law of mechanical science, establishing the perfect passiveness, or incapacity to move itself, of all the matter constituting the globe, on which human intelligences recognize the fact of their existence.

Were it not for the absolute necessity of adopting some kind of theory in order to establish a systematic plan for classifying facts of electrical excitation, and for reducing them to an order worthy of the name of a "Science," it is probable that both the Two-Fluid, and Single-Fluid theories of electricity would have been rejected as unsatisfactory, from their utter discordance with the laws of motion and rest established by the Science of Mechanics.

In the original discovery of the reciprocal Attraction and Repulsion between bodies serving as the pathways of *electric currents*, as well as in advancing original theories for explaining them, Ampère has taken the lead. He supposes that all the phenomena of magnetic attraction, repulsion, and polarity of magnetic bodies, are ascribable to the continuous circulation of electric currents about the minutest atoms as well as about the masses of them, including the huge mass of the terrestrial globe itself;—that these currents circulate in one uniform direction of revolution respectively to the axes of all bodies, and in planes perpendicular to these axes. Around each elementary atom, he supposes these currents to be continuously circulating in a manner analogous to those that environ the little floating Ring of De La Rive, and about the Electro-dynamic Cylinder which has been previously described.

In proceeding to explain the origin and modes of circulation of these subtile currents environing magnetic bodies, Ampère assumes that "each particle or magnetic element may be regarded as constituting a voltaic circuit analogous to a voltaic pile, of which the two ends are united by conductors. The *vitreous* and *resinous* electric fluids are separated at one point of the circuit, and move in contrary directions around the particle, until they meet together, and by their reunions form the neutral fluid," as represented in the figure.

Fig. 109.



"The course of the fluids, during this circulation, is represented by V and R, denoting respectively the paths of the vitreous and resinous electricities emanating from the point E, in the particle of iron, P, and flowing in the directions indicated by the arrows, until they meet and coalesce on the opposite side. But as the effects of the one fluid are exactly the reverse of those of the other, the result is equivalent to the continued circulation of one of the fluids, the vitreous, for example, in one constant direction, E, V, P, R."

This idea of the emanation of two antagonistical kinds of electricity from one point on the surface of a magnetically excited body, and of their continuous separation and divergency to opposite sides in the direction indicated by the dotted arrows, "until they meet and coalesce" as stated in Ampère's theory, is exceedingly complex; and, indeed, the idea of "a *result* equivalent to the continual circulation of one of the fluids" where "the effects of the one are exactly the reverse of those of the other," is absolutely unmathematical.

Ampère's theory affirms that "statical polarity is the consequence of all the unequal distribution of the two electric fluids; while magnetical polarity is the consequence merely of the motion of those fluids, which in magnets are supposed to gyrate in planes at right angles to the axis of the magnet."

Dr. Hare, in his recently published "Objections to the theories, severally, of Franklin, Du Fay, and Ampère," affirms, "Ampère's theories have, in a high degree, the usual fault of substituting one mystery for another; but on the other hand, it has in an equally high extent, the only merit to which any theory can make an indisputable claim,—that of associating facts so as to make them more easy to comprehend and to remember, enabling us, by analogy, to foresee results, and thus affording a clue in our investigations."

"I should consider Ampère's theory more reasonable were it founded upon the existence of one fluid; since in that case circulating currents or vortices might be imagined, without the necessity of supposing an endless and unaccountable separation and reunion of two sets of particles; not only devoid of any property capable of sustaining their alleged opposite gyrations, but actually endowed with an intense reciprocal attraction, which must render such gyrations impossible."

The causes of the separation and reunion of the two different kinds of electricities, springing forth in opposite directions from one point of the surface of a body, to meet and counteract each other at an opposite point, as supposed by the theory of Ampère, is not explained. The student is referred to his fancy, rather than to established facts, to sustain such an extraordinary supposition.

But it is far easier to make objections to theories when advanced, and to pull them down, than to establish a perfect theory which will not share the same fate; but will stand truthful and unshaken, like mountain cliffs, which breast assailing storms. The explorer in physical science, like the explorer in mountain scenery, will often find, that—

"To speak of Snowdon's cliffs sublime,
Is far more easy than to climb."

HOW ARE MECHANICAL IMPULSES IMPARTED THROUGH THE MEDIUM OF ELECTRICITY, PRODUCING THE RECIPROCAL MOVEMENTS OF PORTIONS OF MATTER TOWARD AND FROM EACH OTHER?

Our attention has hitherto been confined to a synthetical view of facts of the propagation of mechanical action through the medium of electric matter.

The question now occurs, how are impulses of mechanical force propagated by means of so subtile a medium as electric matter?

In none of the electrical theories advanced, has it been attempted to explain the originating cause of electric excitation, which serves to propagate mechanical action between portions of matter, to produce the phenomenon of Attraction and Repulsion. All the popular doctrines of electrical action, and indeed of all physical action naturally developed between portions of terrestrial matter both at sensible and insensible distances, appear to be alike based on a supposition of inherent powers, innate in electric matter, as has been premised. All further inquiry into the sources of Natural Motive Power has been precluded by this doctrine, leaving the whole subject still in the same position in which it was left by Bacon, who classified all matter into two kinds, which he denominated "active and passive."

In the course of the preceding investigations it has been shown, that with the extreme velocity of the propagation of electro-dynamic impulses, groupings of elementary atoms may be perforated and dissipated into dust, but they cannot be moved bodily by the direct momentum of impinging electric matter. Consequently it is left for human sagacity to study the laws of the transmission of impulses adapted to such extreme velocities, and to such imponderable subtile matter.

No problem in mechanics has probably ever presented so mysterious, and apparently incomprehensible a subject of investigation, as the present one; for finite intelligence is here necessarily brought to the necessity of grappling with the task of attempting to appreciate the mechanical laws which must govern the almost infinitely rapid movements of an infinitely mobile and imponderable fluid matter.

With such difficulties to contend with, and such feeble powers of intelligence to cope with them, it cannot be anticipated that this most interesting portion of electro-mechanical science can be clearly comprehended, or lucidly explained, with the few facts and discoveries at present constituting all our knowledge of electro-motive powers.

The following observations are therefore presented, rather as leading the way to systematic investigations, than as promulgating established principles of the science of Electro-dynamics.

From long-continued observations of the fact, that no one of the sixty different kinds of elementary substances is capable of putting itself in motion when in a state of rest, or of stopping itself when put in motion, it has been established as a truthful law of mechanical science, that matter is PASSIVE, or INERT, and absolutely powerless. The idea of "inherent" and "innate forces" of matter is rejected by mechanical science. Even the confessedly *innate* powers of vitality to modify the movements of matter, have been shown in the preceding pages to be limited simply to a capability of controlling the directions of electro-dynamic impulses, originating from solar influence, and propagated to produce the food burnt in the mechanisms of animal bodies. The extent of animal motive power has been shown to be very exactly determined by the quantity of food decomposed in the lungs. This fact demonstrates that even the motive power innate in living organic formations is not an *inherent* property of matter.

If there be any novelty in the present view of this branch of physical science, it consists in simply carrying out the primary principle of the inertness of matter unwaveringly through all the details of every possible application of it to producing modified conditions of the states of rest and motion of terrestrial matter. Regarding terrestrial matter merely as occupying space in the heavens, mechanical science considers that it would at this time, as before the creation, "be without form and void," were it not subjected to controlling influences, external to itself. The impalpable condition of a diffused vapor, the quietude of universal silence, darkness, the stillness of death, are the results which mechanical science teaches us would prevail, were not the matter of our terrestrial orb unceasingly subjected to influences of mechanical action external to itself. There is no discoverable cause capable of developing an absolutely original impulse existing within the orb of matter, of which man finds himself an occupant. To a mechanical cause existing at a distance of ninety-five millions of miles from the earth, has been traced every impulse producing states of motion and rest of terrestrial matter.

Considering this remote mechanical cause to be also matter, precisely the same reasoning is applicable to the dynamic impulses propagated therefrom. The source of its motive power must be external to itself, and it can only serve to propagate and modify impulses imparted to it,—not to originate them. This subject will finally be considered in closing these investigations.

Deeming electricity to be matter, or a material fluid, we cannot for a moment conceive that this particular kind of matter can be endued with any *"inherent" power of moving itself when in a state of rest, or of stopping itself when put in motion.*

And deeming, also, the electric matter to be a *perfectly mobile fluid*, the inability to stop itself when put in motion is to be distinctly held out to view in bold relief, as distinguishing this subtile fluid matter from all other kinds of grosser matter, and as practically verifying to the letter the last clause of the preceding law of mechanical science, establishing that matter put in motion cannot stop itself.

To comprehend the idea of a *perfect fluid* in accordance with rigid laws of mechanical science is no easy task, accustomed as men are to observations of the resistance to motion of the grosser fluids of the water and air, which come under daily observation; and the commonly observed resistance to the motion of these fluids, opposed by all solid bodies obstructing their progress, or lying in their way, renders it exceedingly difficult to conceive of a fluid material medium, which will as readily propagate impulses through the most dense and apparently impermeable bodies, such as glass plates, metals, &c., as through void space.

In treating of the propagation of mechanical action through the medium of electric matter, by the direct momentum of electricity it has been shown that this mode of imparting motion to masses of matter is physically impracticable; for electro-dynamic action must necessarily take effect on the mass only through the individual atoms.

There is a reciprocal tendency of bodies toward each other, along the surfaces of which electro-dynamic action is propagated in similar directions. This tendency being at *right angles* to the relative directions of the currents cannot be produced by the direct momentum or impulses of the electric matter in motion. The contact of two spherical elastic bodies, like ivory billiard balls, moving in opposite directions, and striking each other at a particular point on their respective surfaces, it is true, will produce the result of the separation of the balls in a direction nearly at right angles to their courses; but in the case of electrical repulsion, the electric matter is in motion, and not the gross matter of the approximated conducting bodies; and it has been shown that such an impinging of electric matter cannot impart movements to gross matter by its momentum. And in the case of currents similarly moving along the approximated surfaces of conducting bodies, it is impossible to conceive of an approximative movement at right angles to the direction of two forces acting in parallel lines, unless it be by a lateral reaction of some kind or other.

The reaction and pressure of the electrical atmosphere pervading all space, appears to afford the only clue for unravelling the mystery of the lateral action developed reciprocally between two conductors or electro-polarized bodies. With our present knowledge of the facts and principles of electro-dynamic science, it is difficult to conceive of any other mode of accounting for the continuous maintenance of the powerful impulses of mechanical force such as are found to be developed in the form of electro-magnetic force, adequate to sustaining a weight of 3500 lbs., as tested by Professor Henry. The atmospheric pressure is only fifteen pounds to the square inch, and cannot determine this result.

The imponderability of electric matter has been adduced as an objection to the possibility of any influence of the universally diffused electric atmosphere in producing a pressure on bodies immersed therein, by its weight, like that of the ponderable atmospheric air. This objection has been anticipated, in treating of atmospheric electricity, by showing that in accordance with the laws of hydrostatics, we are taught that water manifests no appreciable weight when the scales and body weighed are immersed in the same fluid, and a similar result of course is to be anticipated in regard to the *ponderability* of an all-pervading electric fluid. We are not sensible even of the existence of the atmosphere by which we are surrounded, although it presses on the human body with a force equivalent to a weight of several tons. When the air is exhausted from the two conjoined hemispherical cavities of the Magdeburgh cups, it is demonstrable that this pressure is about fifteen pounds on each square inch; and yet we do not recognize the existence of the air by means of any of our powers of perception, unless *it be by means of its motion*, which is equivocal to mechanical action and reaction. All our knowledge of fluid electric matter is similarly derived from mechanical action and reaction.

Were it possible to create an electric vacuum, like that of an atmospheric vacuum, the exact intensity of the pressure of the electric *plenum* might be precisely ascertained. But inasmuch as this subtile fluid pervades atomic groupings of matter with more or less facility, according to their respective electro-static conditions, no means have yet been devised for testing facts relating to this subject.

If all the space separating the matter constituting our solar system, from the matter constituting the nearest surrounding solar systems, be occupied by electric matter, imponderable and subtile as this electric matter may appear to us, it may nevertheless exceed in absolute weight all the grosser matter of the worlds of the solar systems; and considering infinite space to be pervaded by one shoreless, bottomless ocean of electric fluid, in which all the countless solar systems of the universe are immersed, the extent of the actual intensity of the pressure of this fluid on every square inch of surface of terrestrial matter may be intense, and yet undiscoverable.

Supposing the processes of electrical excitation to be ascribable either to exhausting a portion of space of a portion of the electric matter which naturally occupies such space, or of accumulating therein an additional quantity, which must necessarily occur in the disruptive discharge of an electrical spark, or of the movement of electric matter producing the electro-polarization of bodies, then we have the same grounds for calculations of the pressure of this general electrical atmosphere on the space exhausted of electrical matter, as we have for calculations of the pressure of the local atmosphere of the earth.

The analogies of numerous experiments serve to demonstrate the probability, that the various processes for the disturbance of electro-static conditions of bodies are governed by laws of reacting pressure of an universal electrical atmosphere.

An inverted bottle of water is not emptied of its contents until the air has access to relieve the hydrostatic pressure; and the interior surface of a Leyden jar is not discharged until the electric reaction of the external surface is relieved.

If it be possible to accumulate a constrained static condition of electricity in one portion of a body, it certainly must be possible to reduce another portion of it from a natural static condition.

This being admitted, we have ample scope, for the development of impulses of electro-mechanical forces without any positive limit as to intensity.

In the process of developing impulses of electro-mechanical force adequate to lifting a weight of 3500 pounds, as has been previously narrated, we may consider that the propagation of the electro-dynamic action through the spiral coils wound about the electro-magnet, serves to disturb the natural electro-static conditions of the conjoined ends of the armature, and of the electro-magnet, and to exhaust them of electric matter; or in other words, to produce an electric vacuum between the conjoined ends. The exhaustion of the grosser atmospheric air is accomplished on a great scale beneath the pistons of steam-engines by means of electro-dynamic action propagated by the combustion of fuel; and it certainly cannot be deemed more extraordinary that a vacuum of electric matter may be produced by a similar excitation.

When the atmospheric air is exhausted from between the surfaces of two conjoined bodies, or from between the two Magdeburg cups, a divellent force varying according to the intensity of exhaustion, from an ounce to 15 pounds to the square inch, may be requisite to separate them; and so in regard to the electro-magnet, the divellent force required to separate the armature from the poles may vary in degrees corresponding with the exhaustion of electric matter.

Having considered the phenomenon of cohesion to be due to the similar and continuous propagation of electro-dynamic action about the poles of conjoined atoms, we arrive at the conclusion that *cohesion* is ascribable also to the establishment of an electric vacuum.

The most tenacious cohesion of the atoms of any kind of matter occurs among those of *steel*, a bar of which of the dimensions of one square inch requires a divellent force equal to that of a weight of 120,000 pounds to separate them. This extreme pressure of 120,000 lbs. to the square inch, we may imagine to be a barometrical gauge of the pressure of the electrical atmosphere.

Whilst the continuous propagation of electro-dynamic impulses is exerted to sustain this electrical vacuum, the cohesion continues unchanged. When the electro-dynamic impulses are counteracted by artificial galvanic currents, or by those excitable by the combustion of fuel in furnaces exciting thermo-electrical currents, the restraining force inducing the continuance of the electro-polarization, and consequent vacuum, is withdrawn. The atoms become then reduced to a freely movable fluid state, and are transferable across the liquid to become again restored to their former electro-static condition of grouping at the opposite surface of the battery poles, as occcurs in electro-plating.

It may appear at a first glance to be a visionary supposition, that a subtile fluid like electric matter can be partially excluded from between groupings of elementary atoms, so as to produce an electric vacuum like that of an atmospheric vacuum. That the electric matter can be controlled at all by artificial means, without eluding every attempt to excite it, and to put it in motion in specific directions in the form of currents, might also theoretically appear impossible. And yet we find that we can with great facility induce such a disturbance of electric matter among the molecules of steam as to separate them, and to cause them to occupy 1700-fold more space. In this constrained electro-static condition, they exert a mechanical force equivalent to a pressure of 15 pounds on each square inch of the surface of the vapors exposed to the atmospheric reaction. The formation of steam thus really constitutes one of the most wonderful phenomenon of the development of impulses of natural motive power, on the principle of the exclusion of matter from the occupancy of space, or the formation of a vacuum by electro-dynamic agency.

The gross matter of the particles of the atmopheric air can be excluded from the occupancy of any given portion of space, as is daily effected to a vast extent by the electro-dynamic action of the sun on the surfaces of the seas and lakes of our planet. These molecules of water can be caused permanently to occupy a still greater portion of space by the direct action of electric currents in decomposing them into their constituent elements of hydrogen and oxygen gases. We hence have reason to believe that there must exist laws of electro-static action adequate to excluding not only portions of the atoms of the gross atmosphere from the occupancy of specific portions of space, but also specific portions of the more subtile atmosphere of the universally diffused electric matter. These analogies appear to prove the possibility of the formation of an electric vacuum.

The most intense mechanical pressure that has ever been artificially brought to bear upon oxygen and hydrogen gases has proved insufficient to unite them to produce water. Yet the electro-dynamic action of an electric spark serves to modify the electro-polarity of these two gases, when commingled, so as to reduce them instantaneously to the liquid state of water.

This fact demonstrates conclusively, that the extent of space occupied by groupings of elementary atoms depends on the modifications of their electro-static conditions.

Whether there be more probability of the truthfulness of the preceding hypothesis, than of the present popular theories which have been advanced for explaining the phenomena of Attraction and Repulsion, the reader will best be able to decide, by reviewing the different theories which have been published.

The transmission of impulses of mechanical force between bodies, producing the phenomena of attraction and repulsion resulting from the reciprocal action of electric currents, has been explained by Ampère, one of the most distinguished of modern philosophers, by the hypothesis, that "the immediate cause of electrical attraction and repulsion consists in the vibration of another similar to, if not identical with, that which has been supposed to take place in accounting for the phenomenon of light. If there exist such a fluid, resulting from the union of the two electricities, it must be universally diffused, nearly incompressible, and capable of permeating all bodies; and whatever movements may be excited in it, will be necessarily propagated through it by the friction of the undulatory particles against those that are at rest. With this supposition it may be readily conceived, that the electric fluid will in some degree impart its motion to the surrounding fluid, and that there will be, consequently, a reaction upon the current, which so long as the difference of motion is the same on all sides, will have no tendency to displace it. But if that difference, and therefore the reaction, be less on one part than on another part, (which will be the case when another current is urging the surrounding fluid in the same direction,) the currents will tend to move in the line of the least resistance, or towards each other. On the contrary, when the second current has an opposite motion to that of the first, the resistance will be greatest in the line joining the directions of the two currents, and then will be mutually repulsive."

Œrsted advanced an hypothesis, to explain the reciprocal action between two wires serving to conduct galvanic currents, whereby it is supposed that "during galvanic action, the separation of the two electric fluids, proceeding without intermission in one part of the apparatus, and their reunion being in like manner effected in perpetual sequence along the conducting bodies which complete the circuit, that a continual series of electric shocks take place throughout the whole line of conductors;—a condition which he expressed by the term "electric conflicts."*

Dr Roget remarks that "the *Repulsive action* between the similar electricities," and "the mutual attraction of the two fluids will diminish the outward pressure on the remote sides of the bodies and increase it on the adjacent sides," &c.; but assigns no explanation of the mechanical mode of propagation of this action.

In accounting for the phenomenon of attraction, Pouillet considers that the electric fluid "becomes imprisoned, between the matter of the body and that of the surrounding air; and that when the same balls are charged with opposite electricities, they must become urged toward each other by the effort which the molecules of these fluids make to rejoin one another." And in the case of repulsion the atoms of air are driven away in one direction, and those of the mass of the excited body in the opposite direction.

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* Roget on Electro-magnetism.

Biot illustrates electro-mechanical Attraction and Repulsion, by comparing it to that of a glass globe filled with water and suspended by a string, and having holes in the two opposite sides of it. The globe will move one way or the other in a direction opposite to that of the jet of water issuing therefrom. This mode of action and reaction has been previously examined and shown to be untenable, in treating of the disruptive action from recoiling pointed wires.

The phenomena of electrical action are attributed by Dr. Hare to stationary or undulatory polarizations, "the conducting wire of a battery circuit being, as it were, converted into innumerable small magnets, situated like tangents to radii proceeding from its axis."

Dr. Wollaston supposed that "the electric current must revolve around the axis of the wire, whilst traversing it from end to end, with the utmost rapidity, constituting a peculiar kind of cork-screw movement, partly longitudinal, and partly circular," which he denominated a "vertiginous movement."

Liebeg, after pursuing brief inquiries into the causes of electro-motive power, despairingly asks (chap. 2, page 119), "of what does the force circulating in the conducting wire consist? Is it electrical? Is it affinity? Does it propagate itself along the conductor, like liquid put in motion, or as a series of unities of motion, like sound and light, in passing from particle to particle of a conducting body." He answers by affirming "we are ignorant, and shall remain forever ignorant."

Dr. Thomson observes,* "that with respect to the unknown link which unites electricity to atoms, and keeps it united with them, we are quite in the dark."

Our limits will not permit of further details of opinions which have been advanced for explaining the phenomena of attraction and repulsion.

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* Thomson's Organic Chemistry, vol. 1, page 40.

ANALYTICAL REVIEW OF INORGANIC ACTION.

PROPAGATION OF SOLAR INFLUENCE IN THE MODIFIED FORM OF INORGANIC ACTION BETWEEN PORTIONS OF MATTER AT SENSIBLE DISTANCES.

"The atoms of matter are in some way endowed with electrical powers, to which they owe their most striking qualities."—FARADAY.

In the preceding pages a general or synthetical view has been taken of impulses of mechanical force developed in variously modified forms, constituting sources of natural motive power. These mechanical impulses have all been traced to the electro-dynamic action of the sun on terrestrial matter. To illustrate the truthfulness of the preceding classification of cause and effects of the motion and rest of matter, they now will be reviewed in detail, and severally analyzed.

It has been premised that all our knowledge of the development of impulses of mechanical force producing the phenomena of the movements of bodies, recognized by the terms ATTRACTION, REPULSION, and POLARITY, is limited to the propagation of impulses through the medium of electric matter.

The existence of a subtile matter, diffused through all space, has been described as constituting the medium for the mechanical propagation of electro-dynamic action; and as this same medium has been proved to possess all the requisite essential properties for propagating mechanical impulses, in precisely similar modifications to those popularly denoted by the terms, magnetism, heat, light, chemical action, cohesion, &c., there is no probability that any other peculiar kind of subtile matter occupies space as a necessary medium for producing these phenomena.

The time, therefore, appears to have arrived, in the progressive advancement of human knowledge, when it has become necessary "to affix new ideas" to the preceding popular terms, as denoting simply the variously modified developments of electro-dynamic action, producing the phenomena of ATTRACTION, REPULSION, and POLARITY, which have been exhibited by the preceding *electro-dynamic key*, page 235, and by the *electro-dynamic cylinder*, figure 36, page 240.

We shall commence this analytical review in the regular order in which these phenomena have commonly been treated.

MAGNETISM.

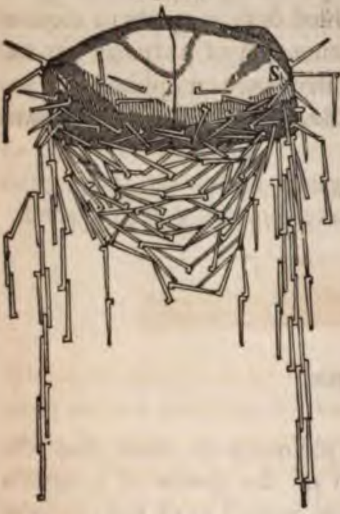
The writings of the ancient philosophers show that the knowledge was possessed by them of the power of a certain kind of stone to attract pieces of iron, as well as of the power of amber, after being rubbed, to attract all light and freely-movable bodies.

This peculiar kind of stone having been first discovered in Magnesia, it was hence termed a "magnet," as electricity similarly received its name from amber, (ELECTRON, in the original Greek.) Later English writers gave the name of LODESTONE to this magnetic iron ore; a term derived from the Saxon word, signifying "*to lead*," as indicating the peculiar power of this substance to *lead* or draw toward itself pieces of iron held near it.

The magnetic properties of the lodestone being found naturally and permanently established in connection with the grouping of the atoms of this peculiar kind of ore found in the earth, it has been designated as a *permanent natural magnet*, to distinguish it from iron, in connection with which similar magnetic properties are *temporarily* and *artificially* excited.

LODESTONE.—The texture of the lodestone is of a solid flinty hardness, as its name implies; its color is a dark brown. This peculiar ore of iron exists in vast quantities in veins in the earth. Every fragment when broken from its natural bed, exhibits a north and south pole, having all the characteristic properties of developing mechanical action, which artificial steel-bar magnets exhibit. It attracts nails and other pieces of iron, as represented in the figure.

Fig. 110.



It was this power of attracting and suspending pieces of iron, which first awakened the attention of mankind to the peculiar properties of magnetic bodies.

The impulses of mechanical force exerted by lodestones are not found to become increased with the sizes of the pieces, the smallest being much more efficient in proportion to their weight than the larger pieces. A small one, once in the possession of Sir Isaac Newton, was capable of lifting a piece of iron of two hundred and fifty times its own weight.

Although the two opposite ends of every piece of lodestone are naturally found to exhibit stronger polar forces than the other parts of the same mass, yet these forces are not limited to the two ends. Every particle is a perfect magnet, as may be artificially shown by pulverizing a lodestone. If formed again into a mass by being kneaded with oil and wax, to give consistency to the particles, it is found that a regular polarity becomes re-established at the extreme ends.

The most powerful natural magnet or lodestone that has yet been discovered, is supposed to be the one recently in the possession of Mr. Peale, of Philadelphia, which is capable of lifting 310lbs, or about six-fold its own weight.

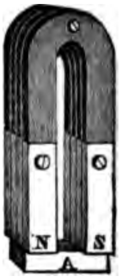
Artificial Permanent Magnets.—In experimenting with the natural magnet or lodestone, it was early noticed that the pieces of iron acted upon and suspended thereby, became also excited to propagate similar magnetic forces, each piece of iron being capable in turn of suspending other pieces of iron. The iron was found to lose its magnetic power immediately on the withdrawal of the presence of the lodestone. But when pieces of hardened steel were similarly excited, they retained permanently the magnetic power and were thence termed *Permanent Artificial Magnets.*

A single bar of tempered steel exhibits a specific extent of propagation of electro-dynamic action. By combining several bars together, the extent of the action has been found to be increased. Magnets constructed of several conjoined bars have been denominated *Compound Magnets.* They are rivetted or screwed together as shown in the figure:

Fig. 111.

For the purpose of arranging both poles to act also conjointly on one body, and for the convenience of applying a cross piece termed an *armature*, or *keeper*, to connect the two ends of poles, as shown at A, in order to sustain, or keep the magnetic powers, (on the principle which has been under consideration in treating of *circuit* of forces,) it is common to bend the bars to the form of a horseshoe as represented in the figure.

Fig 112.

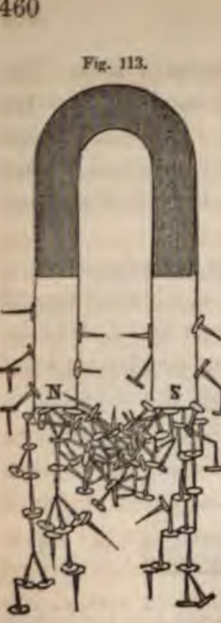


The successive propagation of the electro-dynamic action from one piece of iron to another, is exhibited in figure 113, by inserting the ends of the magnet among some tacks, which become clustered about it.

In this experiment, it is found that the natural magnet does not lose any of its powers by transferring its forces to the nails, and other pieces of iron, in which the phenomenon of magnetism is excited. On the contrary, the powers of the magnets appear to become increased, thus demonstrating that there is no transference of the magnetic properties from one body to another.

This effect of the excitation of magnetic forces in pieces of iron approximated to natural magnets, has an exact analogy to the excitation of electricity by Induction, as re-

Fig. 113.



presented by the insulated conductor, B, page 282. Hence, this mode of excitation has been termed "excitation of magnetism by Induction."

Among the most extraordinary characteristic properties of all the elements of matter may be classed this continuous development of impulses of mechanical force, denominated *magnetic*, resulting from the grouping of atoms of the metal iron, with those of oxygen, sulphur, and carbon, as exhibited in the natural lodestone, and in artificial steel magnets.

There are only two known groupings of the atoms of elementary substances found in the earth, which naturally develop impulses of magnetic forces, viz.:

	Composed of
The Lodestone, or magnetic iron ore,	3 atoms of iron, with 4 atoms of oxygen, forming two different oxides of iron.
and—	
Magnetic Iron Pyrites.	2 atoms of iron, with 3 atoms of sulphur, forming two different sulphurets of iron.
	Permanent Artificial Magnets are composed of
Permanent steel magnets.	98½ parts of iron, with 1½ parts carbon, forming tempered steel.

Mr. Barlow has made a series of experiments to illustrate the comparative forces of attraction between different species of iron and steel, and magnets. The result is stated in decimal numbers, malleable iron being considered as the standard unit.

Malleable iron, - - - -	1,00
Soft cast steel, - - - -	74
Soft blistered do, - - - -	67
Hard blistered do, - - -	53
Hard cast steel, - - - -	49
Cast iron, - - - -	48

The impulses of mechanical force continuously excited by the three preceding groupings of atoms of inorganic matter, so much resemble those exerted by the organic matter of living bodies, that they have continued to excite the wonder of mankind from the earliest records of science to the present day. No surprise is excited on observing developments of impulses by matter organized into the forms of living animals and plants. But when it is discovered that two or three particular kinds of atoms, grouped together by inorganic action into a lifeless mass, are capable of exciting unceasing impulses of mechanical force,—in a manner forming the only exception to the general condition of the passiveness of all other kinds of elementary atoms, this extraordinary fact has appeared like an exception to a general law of nature.

That a lodestone, or permanent steel bar magnet, should be urged toward the centre of the earth has not been deemed extraordinary; because this effect is the result of a general dynamic law of gravity, which acts alike upon all matter. To the superficial observer therefore it may appear, that the above-stated groupings of three kinds of elementary atoms are a special exception to a general law of the inertness of inorganic matter. This supposition, however, cannot for a moment be entertained by any scientific man.

We have then only to look to the general laws of motion and force acting in strict accordance with the established principles of the science of mechanics, for the development of the apparently mysterious forces of a few kinds of elementary atoms of iron, oxygen, sulphur, and carbon, as we find them actually combined in the lodestone, magnetic pyrites, and in permanent steel magnets.

In the first step of our progress of investigation, we establish the fact, that decided magnetic forces are not naturally exerted by the masses of atoms of any one kind of simple elementary substances. Iron, unless united with the atoms of oxygen and sulphur, as in the lodestone and magnetic pyrites, or with the carbon in the steel bar, propagates, naturally, no extraordinary development of the mechanical forces termed Magnetic; and if the relative proportionate grouping of the atoms be varied from that above specified, the farther natural action of these magnetic forces ceases.

If, then, these several kinds of elementary atoms, either by themselves, or when united together in any other grouping than that above stated, are incapable of developing the impulses of mechanical force termed magnetic, we have no choice but to admit the fact, that the grouping of these atoms is essential, as having a paramount influence in determining the manifestation of these natural forces. The 4 atoms of oxygen must be electro-dynamically united with 3 atoms of iron to constitute the lodestone. As observed by Professor Graham, "it may not be an idle hope to look for the elucidation of the cause of magnetism in the peculiarities of the molecular structure of iron." Indeed, there appears to be no other hope in this case, as well as in that of the varied chemical powers of different groupings of atoms, than the modified conditions of the molecular groupings of atoms by electro-dynamic agency, as has been premised at page 71. That these magnetic forces are not absolutely "inherent," even in the lodestone and iron, we learn from the fact of their disappearance and restoration at pleasure by means of various artificial processes.

Not less extraordinary than the permanent development of magnetic forces in steel bars at sensible distances is the wonderful increase of the permanent molecular forces produced by the grouping of only about two atoms of carbon with ninety-eight atoms of iron. This grouping of atoms sustains permanent molecular forces of double the intensity of those sustained by the pure iron, a bar of the former of the dimensions of a square inch being found capable of sustaining a weight of 120,000 pounds, when a bar of the same dimensions of the latter material will sustain but half of this weight.

To impart to the iron this property of permanent molecular, as well as magnetic forces, the ore of the metal is thrice subjected to the electro-dynamic excitation of heat, propagated from fuel produced by solar excitation, viz: first, in the smelting furnace, then in the furnace in contact with organic carbon during the process of cementation, and finally in the forge fire to complete the process of tempering. These details have been anticipated at page 409, in treating of the philosophy of the employment of steel for cutting implements.

That the continuous propagation of the forces in steel magnets is due to the molecular groupings with atoms of carbon, is manifest from the fact that an addition of only one atom more of this substance, to increase the proportion to 3 atoms united with 97 atoms of iron is sufficient to impart to the mass the characteristic properties constituting Cast Iron. A still further addition produces the soft crumbling black lead or graphite.

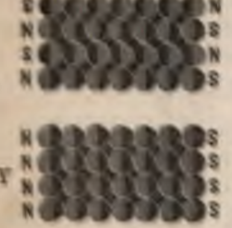
In treating of the grouping of atoms into various Inorganic and Organic formations, frequent reference has been made to the fact of the remarkable differences in the characteristic properties of matter, which are found to result from the different modifications of the propagation therefrom of the electro-dynamic action of the sun. It has been repeatedly shown that the impulses of mechanical force, developed between the parts of approximated bodies, do not originate from any inherent self-motive, and self-directive power. Even in the endowment of certain groupings of atoms into the organic formation of animal bodies, with manifest innate life-power, this power is found to be limited to *modifying* the development and propagation of the electro-dynamic action of the sun in an exact ratio to the quantity of food burnt in the lungs of animal bodies.

The formations of the different kinds of groupings of elementary atoms, as well as their functions in developing impulses of mechanical force, have been considered as limited simply to a power of modifying the propagation of electro-dynamic actions, not to any inherent power of originating it. When, therefore, we regard a fragment of iron ore, exhibiting the power of attracting pieces of iron, we cannot consider the cause of these impulses to originate in the component atoms of the ore; but rather in the cause of mechanical action which originally produced their grouping into the visible mass we behold, and thus enabled it to modify the continuous propagation of the electro-dynamic action of the sun. The circulation of electric currents about the earth is a cause adequate to induce terrestrial magnetic polarity, as has been detailed at page 250, figure 45.

In describing the process of the grouping of atoms into crystals, it has been previously noticed that they become arranged in strict relationship to a specific polarity produced by the continuous propagation of electro-dynamic action about their circumferences, whereby they necessarily present to each other certain portions of their surfaces, distinctly characterized by the relative directions of the circuits of the electro currents about their *equatorial* and *polar* parts, as represented by figure 45 at page 250.

The only reason that suggests itself for explaining the phenomenon of the natural power of the lodestone to modify the propagation of electro-dynamic impulses at *sensible* distances, appears to be the molecular arrangements of the atoms in the solid groupings of the ores of iron, as shown in the figure, where the shaded and unshaded portions of each atom represent its two opposite polarities.

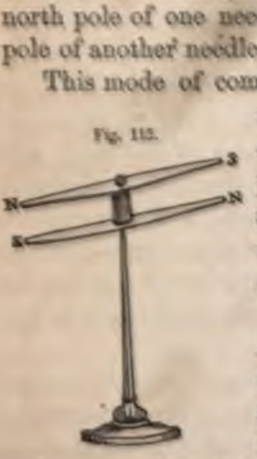
Fig. 114.



On the familiar principle of attraction between the two N and S poles of magnets, it is manifest that the series of magnetic particles of both X and Y are alike acted upon by the respective polar currents with an equal intensity of electro-dynamic impulses. But when the arrangement of the several lines of magnetic particles of X are scrutinized, it will be noticed that the dissimilar poles are alternated in each axial line, presenting at the ends or poles of the mass of atoms the same magnetic arrangement as is artificially produced by reversing the two N and S poles of two magnetic needles; so that the north pole of one needle is directly in proximity with the south pole of another needle.

This mode of combining two needles is represented by the annexed wood-cut. The oppositely directed circulation of the electro-dynamic impulses will exactly neutralize each other, so that this double needle remains stationary in whatever position it is placed, rendering manifest no sign of magnetic power.

Fig. 115.



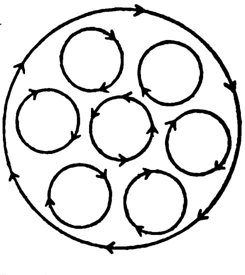
By noticing the comparative molecular arrangement of atoms represented at X, it will be perceived that the relative juxtaposition of their opposite poles is precisely similar to that of the combined STATIC NEEDLE; and consequently their magnetic condition may be deemed to be static; for no signs of electro-dynamic action can be anticipated from a mass of particles crystalized or combined with this peculiar relative alternation of opposite poles. Each completely neutralizes the other throughout the mass. The alternate arrangement of the N and S poles at each end of X, demonstrates this fact.

This peculiar polarized arrangement is the final electro-static condition of the grouping of elementary atoms into inorganic formations; for the *polar* currents which face each other, circulate in similar directions; and the *equatorial* currents also circulate about their respective axes in similar directions through successive series of lines of atoms.

Here, then, we have presented the true and final electro-static condition of grouping of atoms into masses which present the characteristic phenomenon of COHESION, in which there is exerted the most intense electro-dynamic impulses for producing their fixation or solidity without the development of magnetic forces externally to the mass.

In the polarization of a similar series of atoms of the magnet Y, although there may be an equal intensity of electro-dynamic impulses of attraction between the poles of each line of atoms considered with reference to their axes, yet very different is the intensity of the same impulses of attraction between their equatorial currents, which do not coincide but neutralize each other in the interior of the mass by their molecular action and reaction. The currents about the atoms and about the mass are all combined in one similar direction of circulation, as represented by the sectional view given in figure 116. About the poles of all the repective series of atoms as well as about that of the mass, the currents move in the same direction as that in which the hands of a watch move about the dial-plate; and consequently the end or pole presented to the observer exerts the powers of the south pole of a magnet. By reference to the preceding figure, Y, the lateral view similarly denotes all the S poles combined to constitute the single S pole of a bar magnet; and all the N poles are similarly combined to constitute an efficient single N pole.

Fig. 116.



The preceding diagrams may serve to represent the contrast of antagonistical molecular forces, developed internally, and externally to the mass, the former constituting the phenomenon of Cohesion, and the latter that of Magnetism. The more intensely the latter mode of electro-dynamic action is excited, the less intense must become the former, from their relative action and reaction in counterbalancing opposite directions, as denoted by the arrows.

This investigation of magnetic forces carries us back to the previous discussion of the "principles of electro-polarization," at page 365, which is in strict accordance with magnetic polarization.

From the fact that the molecular polarization of Y represents a constrained instead of a final dynamic condition, the preceding considerations would lead us to anticipate theoretically, that this peculiar dynamic condition should be rarely found to characterize groupings of atoms into magnetic bodies, as is found practically to be the case with the above specified exception of the groupings of elementary atoms into the solid form of magnetic ores of iron.

Athough no other groupings of atoms exhibit the remarkable powers of the magnetic forces which iron and its ores develope, yet it is experimentally found that several kinds of metals propagate feeble magnetic or dynamic powers. And nearly all kinds of substances set afloat like magnets on chips of oak in a basin of water, are found to become urged toward each other, and toward the sides of the vessel. This fact demonstrates that there is a common law of attraction applicable to all matter, although to a less extent than to iron and its compounds.

The identity of magnetic and electric action has been demonstrated at page 229, and preceding pages, as being developed by the circulation of electric currents about all the atoms of terrestrial matter, constituting their polarity. The polarity of the masses being constituted of that of the atoms, as has been recapitulated, it follows that the cause of the polarization of atoms must be the cause of the natural excitation of the magnetic forces exhibited by the lodestone, and of the artificial excitation of other bodies.

It has been demonstrated in the preceding pages that the continuous propagation of the electro-dynamic action of the sun [illegible] nate to producing the excitation of impulses of mechanical force which group atoms of passive matter into the static conditions of various inorganic and organic formations of steam, vapors, crystals, and into food and fuel. It remains now to show that the same electro-dynamic action of the sun is capable of producing both directly and indirectly all the phenomena of the static and dynamic conditions of groupings of atoms into *natural* and *artificial magnets.*

The fact of the continuous propagation of electro-dynamic action about the earth's surface in a direction from east to west, has been established by every test that has hitherto been employed.

Whilst one hemisphere of the earth is subjected to a continuous excitation of electro-dynamic action, the opposite hemisphere is continuously propagating these impulses during the night as well as the day, in the form of the electro-dynamic action of "radiant heat;" for it has been shown (pages 44 and 356), that electro-mechanical impulses are capable of being propagated interchangeably in the variously modified forms of heat, light, electricity, and impulses of mechanical force; the latter, in fact, representing all the preceding phenomena.

As the surface of the hemisphere of the earth is of considerable dimension, the continuous propagation of the electro-dynamic action from one part to another necessarily becomes manifest in the form recognizable as the electric currents from east to west (page 250), and this specific direction of the propagation of electro-dynamic impulses about a common axis must also necessarily establish a determinate circulation of similar currents and a determinate polarity of every atom of the whole mass of terrestrial matter.

In the preceding experiments of the action and reaction of impulses of mechanical force developed between two insulated electrically excited bodies, a reciprocal repulsion of their approximated parts ensues, as experimentally tested by the revolving bell-glass, page 207. The more intensely excited side of the terrestrial globe becomes turned away from the sun, producing a continuously revolving movement of it on its axis.

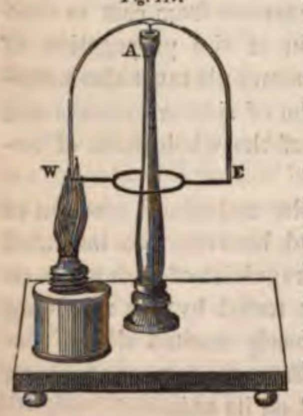
The continuous revolving movement of the earth must necessarily produce a continuous change of the successive portions of its surface presented to the exciting point, and a consequent continuous disturbance of the state of rest of the electric matter existing in connection with the parts of the circumference successively exposed to the powerful influence of solar action. The natural result of these continuous successive disturbances must be a continuous propagation of electro-dynamic action about the circumference of a body revolving near an excited body (pages 278 and 307). There cannot be a movement of one body near another without inducing a disturbance of the electro-static conditions of both bodies, and *a continuous movement must induce a continuous excitation.*

The continuous propagation of electro-dynamic action about the circumferences of approximated revolving bodies being once established, then follows the consideration of the whole train of reciprocal electro-dynamic actions and reactions, which have just come under our consideration, producing all the modified forms of mechanical impulses representing the general phenomena of magnetic attraction, repulsion, and polarity.

This general electro-dynamic action about the mass of terrestrial matter has reference to a direction of impulses about a common axis, and differs from the specific directions of impulses about the axis of each atom of this mass.

The propagation of the electro-dynamic action of the sun about the circumference of the mass of the earth from East to West, constitutes the primary cause of the INORGANIC ACTION between the portions of matter of which this mass is made up.

Fig. 117.



To demonstrate the fact that the continuous electro-dynamic action of the sun is actually capable of propagating continuous electro-dynamic action about the circumference of portions of terrestrial matter, as well as about the circumference of the whole mass of terrestrial matter, with sufficient intensity to produce all the phenomena of Attraction, Repulsion, and Polarity, constituting terrestrial magnetism, a wire frame corresponding to the ring of De La Rue, page 223, may be successfully employed.

The arch of the frame W A E is made of brass wire, with the two lower ends soldered to a cross piece of German silver, which encircles the post, the whole frame being supported by a pivot projecting from A, and resting on the bottom of a small agate cup sunk into the top of the pillar. The frame is thus adapted to revolve freely around the pillar in obedience to the slightest impulse imparted to it.

The thermo-electric excitation of the flame of a lamp is commonly employed in the lecture-room to produce the movement of this frame; but in the present instance it is our purpose to show that the electro-dynamic action of the sun admits of being concentrated by convex lenses or burning-glasses upon the soldered junction of the brass and German silver wires at W, to excite thermo-electric currents about the frame W A E, as has been represented at page 342.

The German silver being a less ready conductor of electricity than the brass wire arch, the electro-dynamic action is determined upwards towards A, and thence downward to E, and to return to close its circuit at W.

By this experiment, the same electro-dynamic action of the sun, which excites the circulation of terrestrial electric currents from east to west about the earth's surface, serves also to excite an electric current to circulate simultaneously about this wire frame. The solar impulses thus become resolved simultaneously into two differently modified currents, and capable of moving in relatively independent directions, acting and reacting reciprocally on each other.

Let the joint W, upon which the solar action is to be concentrated by a convex lens or concave mirror, be arranged exactly in a position *due west* from the central post A. With this precise adjustment of the direction, the electric action is propagated in a circuit about this freely movable frame by the same exciting cause, which propagates electro-dynamic action about the circumference of the earth from east to west. It will be found that the wire frame will remain statically fixed to its east and west position, with one particular side facing the north; and however often it may be pushed aside from this position, it will become swung back to it again, behaving in every respect like a regular compass needle.

If the electro-dynamic action of the sun be now concentrated upon the joint of the wire frame at E, placed exactly *east* of the post sustaining the pivot, the direction of the circulating current will be reversed, and the frame will become swung around thereby until the part E reaches a due *west position* at W. Here it would remain stationary, were it not that by this very movement the joint W becomes swung in turn into the same stationary focus of the solar action; whereby the current is again reversed, and the joint W is again moved around to its first position. This process being continually repeated, a continuous revolving movement is produced, simply by the electro-dynamic action of the sun.

This wire frame would have remained as motionless as any other kind of passive matter, had there been no artificial arrangement of different kinds of atoms, as of German silver and brass, employed by man's device to determine the propagation of the electro-dynamic action of the sun in one specific direction about its surface. This frame constitutes a palpable mechanism, contrived expressly for the special purpose of determining the propagation of the electro-dynamic impulses, originating from the sun, to circulate in a specific direction about the circumference. In this respect it performs only the same functions which the natural groupings of the different kinds of combined atoms of iron, carbon, silica, and sulphur, perform in the structure of the lodestone. The latter is doubtlessly as regularly contrived an electric machine as the former, or as any of the other machines devised by man for determining the propagation of electro-dynamic action in specific directions.

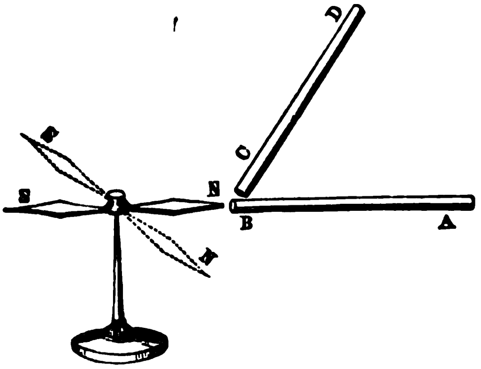
The same analogy, there is equal reason to believe, extends to the grouping of atoms consituting each one of the 60 different kinds of simple elementary substances, as determining their several characteristic properties.

The source of excitation of the lodestone, and of other magnetic bodies are thus traced out to the originating source of solar action, producing general terrestrial electric currents about the earth's circumference, and specific terrestrial currents about the circumference of every atom of the mass.

The fact of the universal propagation of this action admits of a conclusive illustration by simply placing a bar of iron in the direction of the line of dip of a dipping-needle, as pokers are sometimes accidentally left standing in a sloping direction. After a time the continuous action of the terrestrial electric currents excites and establishes circuits about the axes of iron bars or pokers, which exhibit all the characteristic properties of regular bar magnets, whilst they remain in these particular positions.

Bars may have their appropriate currents equally excited in various transverse and miscellaneously counteracting directions, without developing any magnetic excitation. It is necessary to give to the currents one common specific direction, as has been repeatedly noticed, in order to develope a specific polarity. The functions of the wire points of electrical machines, of the copper plate of the galvanic battery, of the current changers of the magneto-electric machine, and of the soldered joint of thermo-electric bars,—are all subservient to propagating mechanical action through the medium of electric matter in one specific direction. So in every process of developing magnetic excitation, the principal expedient resorted to is the resolution in similar directions, of the propagation of the electro-dynamic action about the component atoms of a mass, so that the impulses may be combined to produce palpable effects, instead of counterbalancing and neutralizing each other.

Fig. 118.



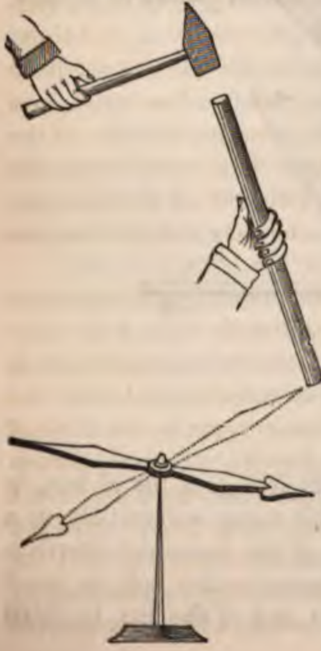
That this result is actually producible in a bar of iron, is demonstrable by holding a bar of this metal horizontally in a direction east and west in the line of the terrestrial currents. On approaching a magnetic needle toward either pole, an equal attraction is developed. But if one end of the bar be lifted from its previous horizontal position A B, to a position, C D, sloping toward the north magnetic pole, in the latitude of the United States, it will now be discovered that the end of the magnetic needle, usually marked N, will be repelled from C, as designated by the dotted lines, N S.

In proportion as the end D is lowered to a horizontal position, the terrestrial currents again act equally thereon, endwise, and cease to determine the electric currents about its axis in conformable specific directions; and then the needle exhibits the same attraction for the ends of the bar indifferently, such as magnets usually exhibit for either end of a piece of iron.

This experiment demonstrates that simply by changing the position of a body in relation to the direction of the terrestrial currents, its natural electro-static condition becomes disturbed, and resolved into a dynamic action corresponding with the action of the artificially excited electric current on the magnetic needle.

But if the bar be acted upon by any mechanical cause of electrical excitation, such as violent percussion, friction, &c., whilst it is held in the line of direction of the dip of a dipping-needle, the influence of the terrestrial electric currents becomes most remarkably augmented, as may be demonstrated in the experiment represented in the annexed figure; where the bar of iron is shown to be held in the same *sloping position*, with its lower end brought near the N pole of a magnetic needle. The electric matter existing in connection with the bar of iron becomes immediately acted upon, as before stated, by the terrestrial currents, when the blow of the hammer disturbs its natural static condition; and puts it in motion in circulating currents in specific directions about its axis, thus imparting to it such magnetic powers of action as to cause the N pole

Fig. 119.



of the needle to be repelled by the similar N pole of the lower end of the bar.

After the needle has come to a state of rest at a distance from the lower end of the bar, strike the upper end of the bar with a hammer. This mechanical action will still further disturb the state of rest of the electric matter existing in connection with the atoms of matter composing the iron bar. The terrestrial electric currents now immediately act upon the more intensely disturbed electric matter existing in connection with the bar, and impart to it such additional electro motive power as to cause the north pole of the needle to swing still further, so that the opposite south pole will finally come within the range of this increased intensity of action and become drawn or *attracted* toward the lower end of the bar, as denoted by the dotted lines.

The overpowering action of the terrestrial currents serves to resolve the latent molecular action into palpable magnetic action.

Analogy leads us to suppose that precisely the same result occurs when the overpowering action of an electrically excited body is brought near a pair of pith balls. There is first a reciprocal attraction between them and the electrically excited body, as there is between the horizontally arranged bar and magnetic needle; but when the molecular action becomes resolved into a constrained polarized action by the overpowering influence of the exciting body, reciprocal repulsion ensues. It is probable that this influence of terrestrial currents on the pith balls of electroscopes, whilst affected by the action of approximated excited bodies, has never been duly appreciated.

From all bodies, except tempered steel, the magnetic excitation speedily disappears on their withdrawal from the immediate influence of the exciting cause. When a steel bar is substituted in place of the iron bar in the preceding experiment, and when the excitation is established to a more intense degree by the blow of a hammer on the end of the bar, its polarization becomes permanently fixed; and it will require an equal mechanical action of a similar blow with a hammer, to reverse the polarity. Hence a steel bar thus treated becomes a permanent magnet, until the electric currents induced to circulate about it are counteracted by some cause of action equally intense to that which was exerted to excite them. The mere shock of the falling of a steel magnetic needle on the floor, will deprive it of some of its magnetic powers, should it happen to strike with the south end in the line of direction of a dipping-needle.

The twisting of a piece of iron wire produces such a modification in the arrangement of groupings of its component atoms, as to determine the propagation of the electro-dynamic action in a specific direction, and to convert molecular forces into magnetic forces. A piece of this twisted wire when balanced on its centre, will behave like a magnetic needle, turning to a north and south position, and attracting iron filings.

That the faculty of propagating magnetic action is not an absolute inherent property of the atoms of any one kind of passive matter, but on the contrary, that it is the result of peculiar groupings of elementary atoms by electro-dynamic agency into inorganic and organic formations, is demonstrable by combining artificially the atoms of the most readily excitable of all magnetic substances—iron—with the atoms of the metal, antimony. This new grouping into an alloy deprives the atoms of iron of their property of becoming magnetic. On the contrary, by combining the atoms of iron with atoms of carbon, sulphur, phosphorus, and some other kinds of substances, these groupings are found to be endowed with additional magnetic power.

The original source of the excitation of magnets being traceable to the groupings of atoms produced by the propagation of the electro-dynamic action of the sun, as previously stated, the *mode* in which this action is continuously sustained in the modified form of permanent magnetic forces, becomes next an interesting subject of inquiry.

In treating of the principles of electro-polarization, page 366, the fact has been noticed, that by extending a series of polarizable atoms until they complete a circuit, or ring, that the palpable external polar forces become resolved into latent internal molecular forces. By sliding a piece of iron along the poles of a U magnet, until it connects the two poles, forming a complete circuit, or circle, the palpable magnetic forces of the magnet disappear, and are found to be resolved into latent molecular forces between the conjoined atoms, whereby the continuity of the circuit is sustained, as illustrated, page 248, by the two conjoined semicircles of iron represented in figure 44. A steel ring is incapable of exhibiting any decided magnetic polarity; for the very sufficient reason, that it has no poles. Between all the series of conjoined atoms forming the circuit of the rings, the magnetic polar action at sensible distances is resolved into molecular action at insensible distances. On pulverizing the steel ring the latent molecular action becomes resolved into sensible magnetic action; and where the former ends, the latter begins.

The magnetic force established between the two pieces of soft iron constituting the electro-magnet and armature, used by Professor Henry in his experiment of sustaining a weight of 3500 pounds, continues after the connection with the battery is broken; as the same force continues permanently, in tempered steel magnets. He states, "After the connection with the battery had been broken, it supported for a few minutes upwards of 1000 pounds; and from year to year the lifter is found to adhere *continuously*, with a force which is only counteracted by a weight of several hundred pounds.

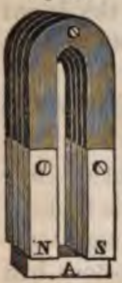
When the conjoined ends are detached for an instant, and then immediately replaced, nearly all the magnetism disappears.

If there be not afforded the facility for establishing the continuous propagation of electro-dynamic action about the axis of a conducting body, in accordance with the preceding arrangement of the circuit of a ring, the intensity of the action, as well as the continuity of it, becomes wonderfully diminished. This appears by another experiment made by the same distinguished professor, demonstrating that when only the opposite ends of one side of the semicircles are conjoined, that less than $\frac{1}{100}$th part of the electro-magnetic adhesion is developed, as compared with that developed when both ends of each semicircle are brought into contact to complete the closed circle of a perfect ring.

The preceding facts are adduced for the express purpose of showing that there exists a law of electrical action and reaction, which sustains a *continuous development of electro-dynamic impulses in closed circuits during indefinite periods of time.*

This conclusion is corroborated by observation of the gradual increase of magnetic forces of such closed circuits by daily adding a small weight to be suspended by the armature. An U magnet, capable of lifting only about 20 pounds immediately after the armature is applied to the poles to complete the circle of a closed circuit, is found to become capable of supporting nearly 40 pounds by daily adding a little more weight.

Fig 120.



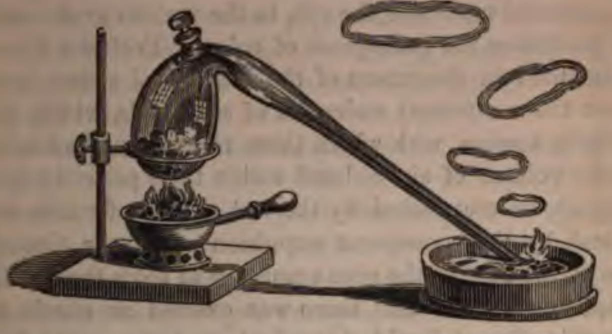
The philosophy of the use of the *armatures*, or *keepers*, employed to connect the poles of magnets for the purpose of sustaining an undiminished intensity of magnetic forces, as shown at A in the annexed figure, is doubtlessly based on this principle of the continuous propagation of electro-dynamic action in these *closed circuits*, or circles of forces. The U magnet, with its appended keeper, represents a complete circuit or ring.

The theoretical supposition of the circulation of electric currents about these rings, as above described, has been subjected to strict mathematical calculations, as stated by Roget, with a view to demonstrate the properties which were anticipated to result from the reciprocal action and reaction of systems of circular currents situated in planes perpendicular to an axis formed by another circle passing through all these centres.

In the experiment for exhibiting magnetic attraction between a revolving plate of metal, held near the poles of a magnet (page 305), it is found, that if a slit be made from the centre to the rim of the plate, so as to cut off the continuity of the circumference of the disc, by destroying the continuity of the propagation of the electro-dynamic action in closed circuits, that there is no possibility of developing electric excitation. The disturbed electric matter having no longer a pathway for its continuous circuit, becomes reduced to ebbing and flowing surges, or undulations, which counteract each other, and exhibit no resultant dynamic impulses, such as become manifest when they are allowed to circulate continuously in the determinate direction of a closed circuit, as is effected by the use of the mechanism of the pole-changer employed in magneto electric machines.

An exceedingly beautiful exhibition of the continuous propagation of mechanical action through the medium of electric matter in closed circuits, or Electro-dynamic Rings, is exhibited by the combustion of phosphuretted hydrogen, from the beak of a retort immersed in a basin of water, as shown in the figure. This gas, it is well known, takes fire spontaneously on coming in contact with the air. Each bubble, on rising to the surface of the water, produces an explosion, and a very white volume of smoke, consisting of phosphoric acid and aqueous vapor.

Fig. 121.



When these bubbles of gas successively explode, they become resolved into beautiful circles of white smoke, which float in the calm air, constituting Electro-dynamic Rings, several of them rising and appearing simultaneously hovering over the basin of water, gracefully waving in curved undulations, but *continuously maintaining their circular structure unbroken.*

When it is remembered that particles of smoke and vapors are commonly repelled from each other and dissipated in the air, the phenomenon of the formation and continuous maintenance of these fairy rings is exceedingly interesting.

Sometimes, in very cold weather, similar Electro-dynamic Rings of smoke may be seen to originate from the vent holes of exploding cannons. On the occasion of a *feu-de-joie*, when the temperature of the atmosphere was very nearly at zero of Fahrenheit's scale, and when two pieces of artillery immediately adjacent to each other were simultaneously discharged, I once witnessed two of these apparently magical rings rising together into the air, and becoming interlocked like the two links of a chain, presenting so remarkable a spectacle as to draw forth a spontaneous burst of applause from the assembled crowd, who witnessed the sight. In tracing the circular formations of these rings of vapor, and their continuous maintenance, as shown in the preceding figure, we have a type of the philosophy of the spherical formation of a soap bubble; for it is only necessary to consider the sphere as made up of a series of such rings.

Newton deemed it worthy of his attention to devote his time to study the phenomenon of the propagation of the electro-dynamic action of the sun from the sides of soap bubbles to the material nerves of the eye, in the various grades of intensities producing the perception of colors. Professor Henry has experimented on the extent of the mechanical action developed between the component molecules of soap suds, whilst inflated. The elastic tension, with which these transparent frail orbs compress the volume of air inclosed within their perfectly spherical formations, he ascertained by the test of their forcible contraction, and by the consequent expulsion of the air through the orifice of the tube of the pipe employed to blow them. He was thus led to conclude, that there was exerted an elastic tension of the thin film of liquid, "equal at least, to several hundred pounds in the square inch."*

With these analogies before us, we may trace out the formation of bubbles, which constitutes the first delightful experiment of every youthful philosopher, to the perfect verification of the preceding principle of propagation of mechanical action through the medium of electric matter in closed circuits, or circles of molecular forces.

There doubtlessly remain more of the recondite principles of science yet to be disclosed by studying the formation of bubbles, than "men yet have dreamed of in their philosophy."

In making experiments to confirm the discoveries of the magnetism of flame, and the recent researches on this subject by Zantedeschi, Professor Faraday has given the following extraordinary details of the circular action of powerful electro-magnets on the flame of a wax taper, arranged between their approximated poles. "When the flame was raised until about two thirds of it was above the level of the axial line, and the poles approached so near to each other (about 0·3 of an inch) that they began to cool and compress the part of the flame at the axial line, yet without interfering with its rising freely between them, on rendering the magnet active the flame became more and more compressed and shortened; and as the effects proceeded to a maximum, the top at last descended, and the flame no more rose between the magnetic poles, but spread out right and left on each side of the axial line, producing a double flame with two long tongues."

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* Silliman's Journal, 1845.

"When the electro magnet was thrown out of action, the flame resumed its ordinary upright form between the poles, at once, being depressed, and re-divided again by the renewal of the magnetic action."

Similar results were found by Faraday to attend experiments on the action of the electro-magnet on *hot* and *cold air*, and in jets of various kinds of gases (substituted in place of the flame), which "were sent equatorially" about the magnet. And such were the remarkable degrees of difference in the action of the magnet on oxygen, hydrogen, nitrogen, and other gases, that he was induced to "think it might not be impossible to separate air into its two chief constituents (oxygen and nitrogen) by magnetic force alone," as the atoms of iron filings are thus separated by magnets from those of copper or lead.

The preceding facts and experiments afford the strongest reason for the belief that the continuous propagation of impulses of mechanical force in the form of inorganic action of *magnetism*, or rather of ELECTRO-POLARIZATION, is ascribable to the continuous propagation of electro-dynamic impulses through the medium of electric matter in closed circuits.

PRACTICAL METHODS OF EXCITING ARTIFICIAL STEEL MAGNETS.

The excitation of magnets was for many ages practised as an art or mystery. Steel bars and needles were sent from afar to men, who acquired fame and fortune from their success in accomplishing this desired result.

The method commonly employed, was to draw over the surfaces of the steel needles or bars, pieces of lodestone, or artificially excited steel bar magnets. This process was termed "touching."

The middle part of the needle, or bar to be magnetized, was placed on one of the ends or poles of the lodestone, and was drawn over that pole in the direction from the middle part to the end of the steel bar or needle. After this operation was repeated a number of times on each of the different sides of the needles or bars, they were turned, end for end, and drawn in a reversed direction over the opposite pole of the lodestone. This operation was also repeated a number of times. By this manipulation, there was artificially imparted to these steel instruments all the permanent magnetic powers which they were capable of receiving by means of the original exciting influence of lodestones, or natural permanent magnets.

The particular end of the steel needles or bars, which may have been drawn over the S pole of the lodestone, was found to have acquired the opposite polarity thereto, or that of the N pole, the opposite extremity of the steel needle being always excited at the same instant with an opposite polarity.

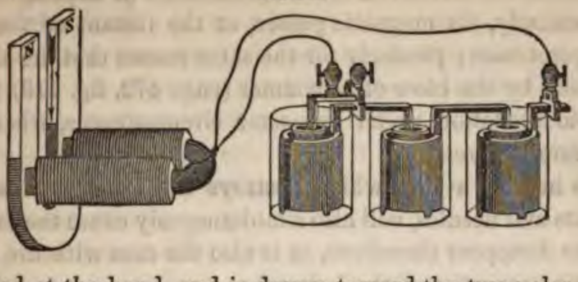
Where the lodestones or artificial magnets are not procurable for the purpose of imparting magnetism to steel bars, recourse may be had to the excitation induced by the natural terrestrial currents which have been described.

A piece of steel, held in the direction of the line of dip of the dipping-needle, becomes indeed an exceedingly sensitive substance to modify the continuous propagation of the electro-dynamic action of the sun; a single blow of a hammer, friction, and every other mechanical process capable of exciting frictional electricity, being adequate to exciting magnetism. I have noticed a large steel drill accidentally arranged in this sloping direction for boring iron, to become so intensly excited as to lift nails held near it. Every machinist who has employed the friction of a file across a piece of iron, or who has employed a steel chisel to cut iron, is familiarly acquainted with the fact that the steel becomes magnetic, as tested by the clustering of the minute fragments about the points of the chisel or file.

The most effective mode of exciting steel magnets now resorted to is the employment of a galvanic battery, propagating electro-dynamic action about an electro-magnet, as exhibited in the figure. This mode has superseded the old plans.

To excite the steel magnets of the U form, the electro-magnet

Fig. 122.



is applied at the bend, and is drawn toward the two poles, so that both poles may be simultaneously subjected to electro-dynamic action. The process is repeated several times on each side of the bar.

To strip this permanent steel magnet of its dynamic powers, it is only necessary to reverse this process by applying the poles of the electro-magnet to the two ends, N and S, and by drawing them toward the middle.

To trace the excitation of magnetism in this case to the originating source, we have first to recur to the reactions of the atoms of the zinc whilst recoiling from the constrained static condition of grouping, to which they have been artificially reduced by the combustion in a smelting furnace of the fuel produced by the electro-dynamic action of the sun, and by the combustion, in the animal lungs, of the food produced by the same action; whereby the animal motive power is developed to move the electro-magnet either upwards toward N S, as represented in the figure, in order to propagate the magnetic excitation to the U magnet, or to neutralize the excitation by moving the electro-magnet in a reversed direction. The excitation of this permanent steel magnet is thus traceable, systematically, to the originating cause of the electro-dynamic action of the sun.

After steel magnets are excited by the various processes that have been narrated, it still requires some care and science to ensure the retention of their forces undiminished in intensity; for the magnetic forces are by no means permanently annexed to bars of steel, as the term "permanent magnets" would seem to indicate.

By accidentally dropping a steel bar magnet, with the S end pointing downward in the line of dip of the dipping-needle, the influence of the terrestrial electric currents will impair, or counteract entirely, its magnetic power, at the instant of the shock of the percussion; precisely for the same reason that the shock of percussion by the blow of a hammer (page 472, fig. 119) induces magnetic excitation, under the same circumstances, where none was before apparent.

The heat of a fire, which destroys the temper of hardened steel bars and needles, will also simultaneously cause the magnetic forces to disappear therefrom, as is also the case with the natural magnetic properties of the lodestone.

The permanency of the excitation of electro-magnets is somewhat dependent on their length. When they are very short, and the poles near each other, the retaining power is exceedingly small, according to Dr. Ritchie's experiment.

On the principle of sustaining a continuous circular arrangement for the propagation of the electro-dynamic action in a closed circuit, which has been previously detailed, it has been found an advantageous expedient for preserving the intensity of the magnetic excitation undiminished, to arrange side by side two bar magnets with their poles reversed, and connected with two pieces of iron extended across the two ends. The four conjoined pieces form the four sides of a closed circuit. The same expedient for forming a closed circuit is conveniently available by means of a single piece of iron extended across from one pole to the other of a **U** magnet.

MARINER'S AND SURVEYOR'S COMPASSES.

The magnetic needle is differently mounted in the Mariner's and Surveyor's compasses, in order to adopt the former more perfectly for use on unstable waters.

To prevent the two rapid oscillations of the needle on shipboard, it is found necessary to affix it to a disc of pasteboard, having the four cardinal points marked thereon, and 28 minor subdivisions intermediate thereto. These are denominated "the points of the compass." They serve to designate more readily, at a glance of the eye of the mariner, the relative positions of surrounding objects.

To maintain the pivot which supports the needle in a vertical position, it is affixed to the bottom of a metallic bowl, which is suspended by an universal joint. The gravitating tendency of the weighted bottom of the bowl always serves to adjust the pivot of the needle vertically, however inclined may be the deck of the reeling vessel.

As none of these difficulties are to be encountered in the use of the compass on the land, a simple naked needle is used in the Surveyor's compass. The card, marked off with the subdivisions of the cardinal points, is affixed beneath the needle to the bottom of its case; and the circles around which the poles traverse, is marked off into 360°. To ascertain the directions of distant objects with great exactness, telescopes, with spider's threads stretched across the glass, are usually employed, and magnifying glasses are added that the fractions of degrees marked on the vernier may be read.

HISTORY OF THE ORIGINAL INVENTION OF THE MARINER'S COMPASS.

The earliest account I have been able to obtain of the discovery of the mariner's compass, was published in London about the year 1668, by John Seller, hydrographer to the king. This writer gives the following history of the mariner's compass, which he asserts "is justly ranked among the greatest wonders that this world affords."

"As to the original invention hereof, modern historians somewhat vary. Some attribute the invention thereof to one John Goia, (or Flavia Goia, as others style him,) of Amalphia, in Campania, in the kingdom of Naples, who only accommodated the superficies thereof with 8 points, that is, 4 cardinal and 4 collateral; and so left the improvement of this invention to be attempted by posterity. Others do entitle the invention thereof to the people of China."

Dr. Gilbert, in his book *de Magnete*, asserts "that Paulus Venetus transported the mariner's compass into Italy in the year 1260, having learned it from the Chinese." And Eudo Vertomanu affirms, that when he was in the East Indies, about the year 1500, he saw a pilot of a ship direct his course by a compass fashioned and framed as those which are now commonly used. And Mr. Barlow, in his book entitled "*The Navigator's Supply*," Anno 1597, relates a story of two East Indians with whom he had personal conference, (one of them was from the Isle of Lazon, and the other of Miaco of Japan,) "who declared, that instead of our compass, they used a magnetic needle of six inches or longer, upon a pin in a dish of white china earth, filled with water; in the bottom whereof they had two cross lines for the principal winds." Also he relates "that the Portugals, in their first discovery of the East Indies, got a pilot of *Melinde*, that brought them from thence in thirty-three days within sight of Calecut; by which it appears that they had the use of the compass."

"But let the invention be attributed to whom it will, 'tis manifestly known to have received its absolute perfection in these parts of the world. But more particularly the completing of this invention is due to the people of Antwerp and Bruges, and also to our own nation, by annexing to the compass twenty-four subordinate winds or points, and also 360 degrees, with a flower de luce to distinguish the North Point."

The difficulties of navigation, before the invention of the needle, are quaintly described by this old writer as follows: "Before the invention of this rare instrument, the mariner's compass, men were directed in their voyages by certain stars they took notice of, especially the Pleiades, Charles's Wain, and the two stars in the tail of the little Bear, which were therefore called *Lode-stars.* Also travellers in the desert of Arabia, and those of Tartaria, were guided by some fixed stars in the nighttime to steer their courses in those pathless, disordered, and inhospitable ways. So seamen were directed by the like heavenly guides, in the untractable wilderness of waters and unbeaten paths of the ocean, before this excellent artifice was discovered. But if the sky happened to be sullied with mists, and the stars to be muffled with clouds, there the most experienced mariner was at a loss, and was constrained to come to an anchor, or to lie by, to wait the reappearance of his Celestial Directors. And if you consult Pliny, he will tell you of the inhabitants of *Taprobana*, now called *Samatra*, who carried birds to sea, because they could not behold the *Pole-star* to sail by, which they did often let fly; and as those birds by natural instinct applied their flight always to land, so the mariners directed their course after them."

"To these and the like difficulties, were men exposed before the invention of this marvellous instrument; and by it posterity is secured with a noble remedy against this grand inconvenience; and a method discovered, as by an immediate messenger from Heaven, to steer an infallible course in the most gloomy nights and tumultuous seas, to gain the desired port by the Providence of the Almighty."

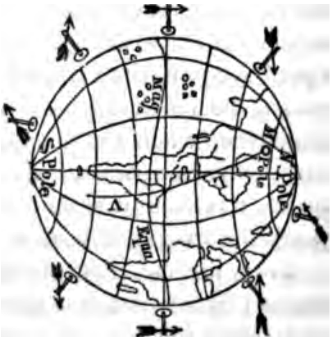
Indeed there appears once to have existed a superstitious reverence for this "marvellous instrument" in the bosom of all those who committed themselves to its mysterious guidance; and even the merchants who committed their property to the great waters, were accustomed to insert in every Bill of Lading a short prayer or invocation for the safety of the ship and its precious freight, thus exhibiting in their mercantile documents a most singular admixture of worldly and of religious hopes.

DIPPING-NEEDLE.

The principle of electro-dynamic action of terrestrial currents which governs the movements of the dipping-needle, has been explained at page 250.

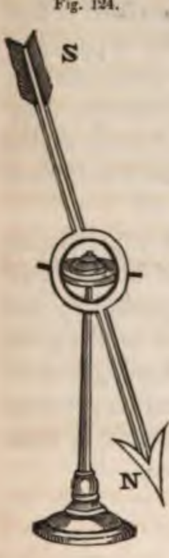
The inclination of the dipping-needle on various parts of the earth's surface, is represented by that of the arrows in the annexed figure. To allow of these extreme inclinations of the needle, a peculiar mounting of the needle is necessary, usually like that of a scale-beam. To exhibit the line of dip with particular accuracy of

Fig. 123.



the angles, a vertical circle, marked off into 360 degrees, is affixed to a base provided with a spirit level, to adjust the instrument to an exact horizontal position. A bar of steel, shaped like an arrow, as represented in the annexed figure, is commonly used for exhibiting the phenomenon of the dip.

Fig. 124.



Every magnetic needle serves to develope the phenomena of the dip, as the one pole or the other becomes depressed in navigating toward the Arctic or Antarctic seas. It is usual to affix to the card attached to the needle of the mariner's compass a small sliding weight, as a counterpoise, whereby the tendency to dip in high northern or southern latitudes is counteracted. This counterpoise requires to be slipped further toward the end of the needle, in proportion as the mariner advances toward either pole of the earth. Notwithstanding this weight, the compass needle becomes nearly useless to the navigator on approaching the magnetic poles of the earth.

The fact of the depression of one end of a balanced piece of tempered steel by the action of the terrestrial electric currents, admits of illustration by magnetically exciting the tempered steel scale-beam of a small balance for weighing gold. If the end of the beam in which the polarity is excited, be arranged to point toward the north magnetic pole of the earth, it will immediately preponderate, precisely as if it were heavier. On reversing its relative position this preponderance disappears. For this reason a delicately tempered steel scale-beam for weighing gold may be made to exhibit a perfect equilibrium when held with one particular end directed toward the north magnetic pole of the earth, and a decided preponderance when the position of the end is relatively reversed. For this reason brass, instead of steel, should be employed for the construction of scale-beams, designed for determining with nicety the weight of bodies.

From the fact that the magnetic pole of the earth has been attained by adventurous navigators, whilst the axial pole of the earth never has been, it is manifest that these two poles are distinct from one another. Indeed it has been found that a magnetic polarity of the earth is discoverable by the test of the dip of the dipping-needle in several portions of the polar regions.

By reference to the reversed position of the magnetic needles, represented at page 250, it appears that the same pole of a needle which points toward the north pole of the earth, and toward the north star, becomes completely turned about by the increase of the dip, until at the north pole of the earth it points directly from the same star. This fact demonstrates that the term "north," popularly applied to designate that pole of a compass needle which in the equatorial regions of the earth points to the north, is truthful only to a limited extent. This investigation leads us to note here the common popular error arising from this misapplication of the term "north" to designate the pole of the compass needle, which has all the characteristic properties which really constitute it a *south* magnetic pole.

POPULAR MISNOMER OF THE POLES OF COMPASS NEEDLES.

As the two similar poles of magnets always repel one another, this fact is sufficient to prove that the *north* pole of the earth and the *north* poles of magnetic needles cannot be endued with a *similar* kind of polarity. In describing terrestrial polarity at page 250, figure 45, it has been shown that the north pole of the magnetic needle, which when stationed at the equator points toward the north polar star, when transferred to the north magnetic pole of the earth points therefrom in an opposite direction, as tested during the Exploring Expedition of Captain Ross in the Arctic regions. Hence the term "north" pole, applied to designate the pole of the needle which points to the north polar star, when at the equator, would be termed the "south" pole, as applied to designate the same end of the needle when viewed in its exactly reversed dipping or vertical position in the Arctic regions.

This application of the same name to designate the magnetic polarity of the earth and of compass needles, proves a frequent source of perplexity and error to students in their initiatory introduction to this branch of science. To rectify this misnomer, it will be necessary always to bear in mind that the north magnetic pole of compass needles must be endued with the same polarity as the south magnetic pole of the earth, that is, that the "*north*" poles of needles are really south poles.

This embarrassing misapplication of the same names to the opposite poles of magnetic needles and of the earth, has become so fixed by long and habitual use, that it is now too late to remedy it by attempting to affix new names to old things.

The simplest available plan to obviate this error at the present day is to affix a simple mark or * instead of the usual letter N, to the pole of the needle, with the clear comprehension that the *star-marked* pole represents the characteristic properties of a SOUTH MAGNETIC POLE.

This continual tendency of the compass needle to become more and more inclined from a horizontal position at the equator to a sloping and vertical position at the poles of the earth, has been denominated

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VARIATIONS OF THE MAGNETIC NEEDLE.

A variation of the line of dip of the dipping-needle, and also of the horizontal positions of the compass needle when transported by mariners to different parts of the earth, has been noticed by long-continued observations. The first observation of the local variations of the needle in the compass box, used by Columbus in his adventurous voyage of discovery, so shook the faith of his alarmed crew in the truthfulness of this instrument to point out their true pathway across the trackless ocean, that it required the bold address of that energetic navigator to induce their assent to advancing further under its erratic guidance.

There appears to be a meridian line extending around the circumference of the earth, although a very crooked one, in which a magnetic needle is always found to point due north; and when removed a short distance aside either to the eastward or westward of this line, it is found to *vary* from pointing due north. By the industrious and diligent observations of Professor Hansteen, Duperry, and M. M. Marlet, a vast number of observations of the variation of the needle on different parts of the earth's surface have been collected and compared together, so as to form a new "Magnetic Chart of the Variation of the Needle." There appear, from the result of these observations, to be two distinct north, and two opposite south magnetic poles, as connected with terrestrial magnetism.

During the explorations of Captain Ross to find a northwest passage through the Arctic Ocean to the Pacific Ocean, he reached the magnetic pole, situated to the north of the continent of America, in west longitude 96° 45′ 48″, and in north latitude 70° 5′ 17.″ The magnetic needles of the compass whilst at this place lost all their directive power; and when allowed freedom of motion in all directions, as when mounted so as to serve as dipping-needles, they all stood with their *north* ends pointing downwards toward the centre of the earth, the *dip* being within only $\frac{1}{60}$th part of one degree from an exactly vertical position.

The line of *no variation* of the needle is stated by Hamilton to begin in latitude 60° westwardly of Hudson's Bay, proceeding in a southward direction through North America, and passing the Antilles and Cape St. Roque, until it reaches the Southern Atlantic Ocean. This line is designated on the circumference of the globe, represented in figure 123. In the southern hemisphere this line continues almost straight, bending round the eastern part of South America, a little south of the equator. This constitutes what he terms "the *western* line of no variation." The "*eastern* line of no variation" is extremely crooked, being swerved into "loops and inflexions of the most extraordinary kind, indicating the action of local magnetic forces."

The "line of no variation through the United States, may be traced on the map by drawing a line a little concave to the east, from the northwestern angle of Pennsylvania, or Lake Erie, to Cape Lookout in North Carolina. At all places to the west of this line in the United States, the needle points to the eastward of the true north meridional line; and in all places to the east side of this same line, the variation is west. Thus the variation at Cincinnati is about 4 degrees east, and at Philadelphia, about the same west."

A needle stationed at one portion of the earth's surface has been found to vary less from a uniform line of *dip*, than from that of a horizontal meridional line.

The extent of the variations of the needle both as to vertical and horizontal swervings, are discovered to be now diminishing at the rate of about 3′ annually, as ascertained by observations made during the past half century, at the Greenwich Observatory, near London.

PERIODICAL, ANNUAL, AND DAILY VARIATIONS OF THE NEEDLE.

The magnetic poles of the earth do not remain fixed and unchangeable, like those of the true poles constituting its axis of rotation; but there is not only a regular swerving in the direction of the magnetic needle during a long series of several hundred years, but also during the different seasons of each year, and during the different hours of each day.

It is the opinion of Hansteen, from the result of numerous observations, that the points of the two northern magnetic poles become transferred with a regular motion round the globe from west to east, in an oblique direction; and the two southern ones from west to east, also obliquely, in the following calculated periods of their revolution.

The strongest *north* magnetic pole	in	1740	years.
The strongest *south* do.	"	1609	"
The weakest *north* pole		860	"
The weakest *south* pole		1304	"

The following table exhibits the progressive periodical changes in the variation of the needle in different localities in the United States.

*Variation and Dip of the Magnetic Needle in different places in the United States.**

Station.	Lat.	Lon.	Variation	Date.	Computed annual motion.	Date.	Dip.
Burlington, Vermont,	44°27′	73°10′	+7°30′	1818	+5° 8′		
			8 50	1834			
Chesterfield, New Hamp.	42 53	72 20	6 0	1820	5 1		
			7 45	1836			
Waterville, Maine,	44 27	69 32	12 08	1835			
Deerfield, Massachusetts,	42 34	72 29	5 28	1811	4 9		
			7 57	1837			
Cambridge, "	42 22	71 7	7 30	1810	5 0	1840	74°19′
				1840			
Providence, Rhode Island,	41 51	71 26	7 0	1831		1834	74 2
				1840		1839	73 59
New Haven, Connecticut,	41 18	72 58	4 35	1819	4 4	1840	73 26
			6 10	1840			
Albany, New-York,	42 39	73 45	5 45	1818	4 6	1833	74 51
			6 47	1836		1840	74 45
New-York City, "	40 43	74 1	4 40	1824	3 6	1840	72 55
			5 40	1837			
Philadelphia, Penn.	39 57	75 11	2 25	1813		1834	72 02
			+3 52	1837	3 2	1840	71 55
Milledgeville, Georgia,	33 7	83 20	—5 30	1805			
			4 40	1835	2 3		
Mobile, Alabama,	30 40	88 11	8 10	1809			
			7 12	1835	1 5		
Cleveland, Ohio,	40 10	80 52	3 10	1820		1840	73 14
			2 31	1838	4 4		
Cincinnati, "	39 6	84 27	5 15	1825		1841	70 27
			4 46	1840	3 1		
Detroit, Michigan,	42 24	82 58	3 13	1822		1841	73 36
			2 0	1840	4 0		
Alton, Illinois,	38 52	90 12	8	1835	2 4	1841	69 34
			7 45	1840		1819	70 30
St. Louis, Missouri,	38 37	90 17	8 49	1835	2 3	1841	69 28

In the course of one hundred and seven years, ending in 1842, the variation of the needle has been restored in the locality of Providence, Rhode Island, to the point from whence it began to swerve in 1735, when the variation was 8° 39′ west. The degree of least variation was 6° 10′ west in 1690, and it increased 2° 29′ in 45 years, to 1735. The variation is now on the increase at the rate of 6′ or 7′ per year.†

Professor Lloyd has stated as the result of the observations made at the Dublin Magnetical Observatory, during several years at regular intervals of every two hours, by day and night, that there appears to be *regular variations in the direction and intensity of the earth's magnetic force.*

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* From Silliman's Journal, vol. xliii.

† See Silliman's Journal, Vol. 44, No. 2, page 314, communicated by M. B. Lockwood.

The mean daily variations of the needle for the entire year exhibit a small easterly movement of the N, or * marked pole of the magnetic needle during the morning hours. The variation reaches its maximum about 7 A. M. After that hour the marked pole moves rapidly westward, and reaches its extreme westerly position at 1 hour 10 min. P. M. It then returns to the eastward, the easterly deviation becoming a maximum about 10 P. M., the mean daily range being = 9° 3 minutes; and it appears, on an examination of the facts brought to light by these observations, that the diurnal changes in the directions of the magnetic force are quite regularly connected with the diurnal revolving movement of the portions of the earth's surface successively presented to the exciting influence of the sun at the time of its rising and setting.

The extent of these annual variations is not found to be uniform on all parts of the earth's surface, differing materially in different places, and even in the same place at different seasons of the year. The electro-dynamic action of the sun's rays become more intense in summer than in winter. In June and July the diurnal variation in England has attained to 19′ 6″, and in December 7′ 6″. In America the diurnal variations are more considerable, and also more irregular. At the magnetic equator of the earth they vanish entirely, and on the south of the equator these variations reappear in an inverted order.

In addition to these regular variations, the magnetic needle is acted upon by all ordinary electrical excitations, whether artificially produced by approximate currents of electricity from a voltaic apparatus, or thermo-electrical apparatus, or by the excitation that naturally occurs during the existence of certain meteoric phenomena, such as the Aurora Borealis, the eruption of a volcano, and a flash of lightning. By the intense action of the latter the polarity itself of the needle becomes often reversed, or entirely destroyed, as has been previously stated.

The *annual change* in the variation of the needle, it is stated, depends on the position of the sun in reference to the equinoctial solstitial points. The needle has been found to retrograde toward the east during the three months from the vernal equinox to the summer solstice; and during the remaining *nine* months of the year its general motion is to return toward the west.

As the compass needle is subjected simultaneously to both a vertical and horizontal daily variation, as above described, its pole consequently "each day describes a cone, whose base would be an ellipse or some other curve more or less elongated in different parts of the earth."

LOCAL VARIATIONS OF THE MAGNETIC NEEDLE.

As the previous details have demonstrated that the compass needle is caused to swerve readily by the propagation of electro-dynamic action or electric currents through approximated conducting bodies, to this cause are we to ascribe all of its local variations. The terrestrial currents are doubtlessly diverted from an exact line of an east and west direction by differences in the conducting powers of veins of metallic ores, and even of subterranean water-courses percolating through dry soils. Whatever cause may influence the propagation of the terrestrial currents, the needle must detect the disturbance. The local variations of the surveyor's compass may therefore be resolved simply into its functions as a galvanoscope.

On shipboard the needle of the mariner's compass is exposed to more frequent disturbing causes of perturbation. The local distributions of masses of iron used in the construction of ships, and in their armaments, as also in the cargoes of metals, with which they are often freighted, always affects to a greater or less degree the usual polarity of the needle. For these special reasons a careful navigator should avail himself of the first opportunity afforded him on his voyage of experimentally testing the local variation of his compass needle by reference to the polar star. To render this test complete, observations should be made whilst the course of the vessel is altered to various points of the compass: for the mere change of a ship's course from an easterly to a westerly direction, in northern latitudes, has been known to be attended with a variation of from five to fourteen degrees.

This cause of the local variation of the needle, is found to become diminished on approaching the equator, and to receive increased force on approaching the south pole.

With a deviation of 10° of the needle, the vessel may depart more than a mile and a half from the reckoning, in sailing only about ten miles. On long voyages, during which the state of the weather frequently prevents the taking of proper nautical observations, a vessel may be thus steered by the compass so widely as to diverge many leagues from the supposed line of direction in her course; and may become shipwrecked on shoals or rocks, from which the mariner may suppose himself to be far distant, whilst lulled into a sense of security by reliance on the magnetic needle. These deviations in the steering of vessels from their true courses, is usually attributed by mariners to the action of currents.

It is stated that the same compass will not even indicate the same direction of polarity when removed from one vessel to another. It cannot, therefore, be a matter of wonder that the vessels of a fleet soon become separated whilst steered by the same points of the compass.

It is a common practice to have two compass needles in different parts of the vessel, to serve in some degree as a check to correct their respective variations.

Where the cargoes of vessels are composed of iron, and where armaments of ships of war and the massy machinery of steamboats are composed of this metal, the needle is found to traverse very irregularly.

It was stated nearly thirty years ago in a public journal, that the captain of a small vessel on the coast of New England, finding the needle of his compass to become useless from the local attraction of a cargo of cast iron ware, placed the compass box directly inside of one of the iron kettles, whereby the more immediate attraction of the surrounding iron became so equalized on all sides of the needle, and so much stronger than the disturbing attraction of the more remote pieces of metal comprising the cargo, that the needle returned to nearly its true north and south position.

Barlow has applied this principle of the neutralization of local attractions by arranging the magnetic needle in a hollow sphere of iron, of the weight of about four pounds, which arrangement has been found adequate to neutralizing the local attractions of the iron cannons of ships of war. Captain Parry states, "When I consider the many anxious days and sleepless nights, which the uselessness of the compass in the northern icy seas occasioned me, I really should have deemed it a kind of personal ingratitude to Mr. Barlow, as well as a great injustice to so memorable an invention, not to have stated my opinion of its merits, under circumstances so well calculated to put them to a satisfactory trial."

In practical land surveying, it is necessary for the surveyor to note on his plats, or charts, the variation of the needle at the time the surveys are made, which will serve to correct the variation, and to give the true meridional line. Otherwise the courses he lays down by the needle of his compass, will only serve to give the angles and relative courses of his lines, and not the true cardinal points and bearings of the bounds relatively to each other.

Indeed, so uncertain are the courses indicated by the magnetic needle of the surveyor's compass from local disturbing causes, as well as from the regular annual variations of the needle, that it is not found safe to place much reliance on the courses, as laid down in plats, in lawsuits relative to contested bounds and lines of land. Actual admeasurements of distances by the chain, are deemed more certain than the courses laid down; and both are deemed more uncertain, and liable to error, than fixed bounds. The latter are consequently admitted as preferable and paramount proofs in establishing contested boundaries of lands in legal proceedings.

MAGNETIC OBSERVATORIES.

The variations of the magnetic needles stationed on different parts of the earth's surface, and the daily disturbances, or perturbations of them, which have been narrated, have been watched with great interest by philosophers. During long courses of observations of these variations of the needle, it was discovered that they are subject to sudden starts from their usual north and south position; and on simultaneous observations of several different needles, stationed at remote distances from each other, it was discovered that they are all swung around in the same direction, and at the same instant of time.

For the purpose of comparing these movements, or perturbations of magnetic needles, baron Van Humboldt instituted a regular course of hourly observations, which he vigilantly continued in an open garden in Berlin, during many successive days and nights. He states, that he was frequently surprised to notice the occasional violent oscillations of the needles, which occurred at intervals. But so much personal exposure attended these protracted observations when made in the open air (as is necessary for the purpose of escaping beyond the influence of the local attractions of the iron usually employed as nails and bolts in ordinary architectural constructions), that they were necessarily interrupted during inclement weather. It was hence found necessary to erect edifices expressly for the purpose of being used as "magnetical observatories." In selecting the materials for such structures, all iron is studiously excluded. Even in bricks, which have been unequally baked, magnetic properties have been detected, and in some experiments they rendered manifest an evident polarity. For this reason, bricks of this description were rejected in the construction of the Magnetical Observatory, at Greenwich, near London.

The construction of such buildings being beyond the means of individual experimentalists, Humboldt succeeded in interesting scientific associations in several of the countries in Europe to undertake these investigations; and through the influence of scientific men, numerous observatories have been established by various governments on different parts of the earth's surface.

Observatories have been established by the English government in Dublin, in Toronto (Canada), St. Helena, Cape of Good Hope, Van Diemen's Land, Madras, Semla, Singapore, and Aden; by the Austrian government, at Prague, and Milan; by the French, in Paris, and at Algiers; and by other governments, at Breslaw, Munich, the Hague, Gottingen, Berlin, Brussels, Cairo (in Egypt), Pekin (China), &c.

In the United States there is a national magnetic observatory the city of Washington, and one in Philadelphia, and another Cambridge (Massachusetts). The observatory in Washington well worthy of the attention of the intelligent traveller, as one the most interesting objects in the capital city of this country.

The object of establishing and maintaining these observato-s is, to make simultaneous observations of the movements or turbations of magnetic needles in distant places, in order to ablish the truth of the fact of their simultaneous movements. ree distinct phenomena of their movements are designed to be efully watched and noted by two hourly observations, taken ring the day and night, Sundays excepted, viz.:

1st.—The *horizontal* swervings of the marked pole of the edle either toward the east or west.

2d.—The *vertical* swerving, or dip of the pole of the needle, and

3d.—The *intensity of the action* of the magnetic forces, as mea-red by their power of twisting around a silk cord, or filament, ich serves to suspend the needles.

On certain days fixed upon in each year, simultaneous obser-tions have been made at intervals of 5 minutes each, to ascer-n the slighter changes during 24 hours.

This system of observations was commenced in 1839, and has en continued, with few exceptions, in most of the observatories til the present time.

From the preceding facts, it is inferred, that although there ists a general cause of magnetic forces, affecting, simultaneous-all parts of the earth, yet, as there is a daily regular fluctua-n corresponding with the relative position of each part, suc-sively, at stated intervals, after it has been exposed to the in-ence of the sun, the magnetic forces are shown to be intimately nected with the excitation of the same. Thus, the theory of the ntity of electric and magnetic excitation, becomes corroborated these experiments, as has been explained in the preceding pages.

Sir John Herschel states, that the number of separate observa-ns made at 30 different stations, have amounted to about six llions. Great labor is necessary to arrange them in relative ular forms, for comparison.

It appears from the general result of these observations that e simultaneous magnetic impulses of mechanical force, in relation both to *direction* and *intensity*, are in a state of continual fluctuation, "being scarcely stationary from one minute to another." The marked poles, or ends of each of the several needles arranged in all the observatories at remote distances from one another, as, for instance, at Leipsic, Upsala, Gottingen, Berlin, the Hague, &c., are frequently discovered *to be moved at the same instant, and in the same direction*, either to the west, or to the east.

This remarkable coincidence is found to be extended, even between the distant continents of Europe, and the United States. According to the statement of the result of Dr. A. D. Bache's observations in Philadelphia, and those of Professor Lloyd, in Dublin, it appears that at the instant, when the needle was most agitated in America, it was also unusually disturbed in Ireland.

By observations made by Professor Henry, in Albany, N. Y., on the 19th of April, 1831, during the occurrence of the phenomenon of the aurora borealis, a remarkable perturbation of the magnetic needle was seen, whilst a simultaneous perturbation of the needle was noticed by observations made at Woolwich, near London. Professor Henry, in communicating the results of his observations, (Silliman's Journal, 1832,) observes, "It appears to me highly probable that the disturbing cause was not only common to both places, but was also active at the same time in a great part of the globe."

The fact of the occasional movements, or perturbations of all magnetic needles from their usual state of rest in a north and south position, serves to demonstrate that there are occasional disturbances or waves of the whole electrical atmosphere universally diffused throughout all space. Any cause of great electrical disturbances on one part of the earth, such as the eruption of volcanoes, the powerful discharge of lightning in thunder storms, and the flashing of the aurora borealis in the upper regions of the heavens, are all sufficient causes to produce tidal waves, or undulations of the electric fluid, which may propagate impulses of mechanical force to act upon the needles stationed on the parts of the earth's surface most remote from them. It has been found that the occurrence of the aurora borealis in Siberia, or in north America, actually disturbs the magnetic needle in Paris. Arago deemed it probable that even the aurora, at the south pole of the earth, may extend its electro-motive power to the same city.

In order to compare the perfectly simultaneous movements of magnetic needles stationed on remotely distant parts of the earth, recourse has been had to drawing a series of lines near each other across a sheet of paper previously prepared with a series of vertical lines, denoting the time of observation. When one needle is swerved from its position at any one moment of time, the other needles being similarly affected, the lines drawn to represent these disturbances, form "magnetic charts." When these charts, from remote stations, are reduced to a tabular form, and are compared together, they represent to the eye of the superficial observer, such a complete system of arrangement of parallel lines, that they sometimes appear to be studiously drawn to conform to each other, so uniformly do the "ranges of the divergency of the needles conform to each other in these Tabular Magnetic Reports."

When it is considered that this wonderfully general electromotive power is thus instantaneously propagated to all parts of the earth by every cause of disturbance occurring on any spot of its surface, it cannot be a matter of surprise that the compass needle is almost continually disturbed by local causes acting on some part or other of the earth's surface.

The mechanical action propagated through the medium of electric matter on the surface of the earth, might probably affect annoyingly the electroscopic nerves of sentient beings living thereon, were it not readily and equably diffused by means of the conducting powers of the salt water, which covers nearly three-fourths of its surface. The superior conductibility of salt water of the great oceans may have reference to facilitating its electrical equilibrium, otherwise far more violent perturbations of the needles would probably be discovered in magnetic observations. All the discoveries made by means of the long-continued vigilant watchfulness maintained in these observatories, demonstrate the true character of the needles used in mariners' and surveyors' compasses to be that of galvanoscopic instruments, operated upon by terrestrial electric waves and currents.

It has been shown that every movement of one body near another serves to disturb the state of equilibrium of the electricity naturally existing in connection therewith, and to induce the movement of the electricity in the form of currents; and it has been also demonstrated that the movement of electric currents over the surfaces of approximated bodies, serves to develope impulses of mechanical force precisely identical with those exhibited by bodies which are denominated "magnetic." All we know of "magnetism" is the development of this action of mechanical forces; we have therefore the strongest reason theoretically to consider every kind of elementary matter capable of transmitting electric currents, or of being inductively excited, as being also capable of developing impulses of mechanical force, equivalent in every respect to those which are popularly ascribed to magnets. Experiments appear to justify this theory, and to lead to the conclusion that the natural motive power, termed magnetism, is universally excitable in connection with all matter by the propagation of the electro-dynamic action of the sun.

The preceding details have exhibited the universal propagation of magnetic action through the medium of electric matter over the whole extent of the mass of the terraqueous globe. For the purpose of demonstrating the propagation of the same magnetic action between all kinds of groupings of the individual atoms of terrestrial matter, as well as of iron, nickel, and a few other substances to which magnetic action was once deemed to be limited, Coulomb made the following experiments.

The various kinds of substances were reduced to the shape of magnetic needles, about one inch long, and $\frac{1}{30}$th of an inch thick, and were suspended by a silk fibre from the top of a glass receiver, which served to exclude all currents of air. The receiver was placed so as to inclose the opposite poles of two powerful bar-magnets, each formed of four bars of steel tempered at a white heat; and the number of oscillations of the needle between these poles was noted. He found that "*all substances whatever, when formed into small needles, turned themselves in the direction of the poles of the magnets, and after a few oscillations, finally settled in that position.*" When these suspended bodies were moved aside a very little way out of their position of equilibrium, they immediately began to oscillate round it, the oscillations being always performed more rapidly in the presence of the magnets than when they were removed out of their influence.

He thus found that all kinds of substances, such as metals, stones, animal and vegetable substances, including woody fibres, flesh, blood, bones, &c., rendered manifest indications of magnetic action or forces.

He announced to the Institute of France, in the year 1802, "*that all bodies whatever are subject to the magnetic influence, even to such a degree as to be capable of accurate measurement.*"

These experiments of Coulomb serve to prove in detail what is rationally to be calculated upon from analogy, of the universal circulation of terrestrial electric currents in inducing universal polarity and universal electro-dynamic action, as has been previously established in treating of terrestrial electric currents.

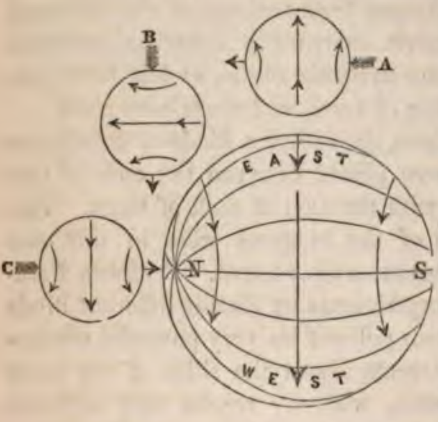
In Coulomb's investigations, the different kinds of substances subjected to experiment, were placed between the ends of two bar-magnets, and in a line with the axis of each of them. The *polar* currents of the ends of the magnets were in this case brought to act upon the substances thus tested. Professor Faraday instituted a course of experiments by placing different kinds of substances between the two poles of his very powerful electro-magnet. The *equatorial* currents about the sides of the poles were thus brought into action, whereby results very different from those stated by Coulomb, were found to occur. The action and reaction being confined by this peculiar arrangement to the sides instead of polar ends of the bodies, they were discovered to assume a transverse or lateral position as compared with the positions which the same bodies assumed in Coulomb's experiments.

This modification of the exposure of bodies between two magnetic poles, was assumed by Faraday, to indicate the existence of a transverse magnetic force, to which he has given the name of DIA-MAGNETISM.

ON THE DEVELOPMENT OF MAGNETIC ACTION BETWEEN THE EQUATORIAL PARTS OF BODIES CONSTITUTING "DIA-MAGNETISM."

In the preceding discussion of the development of electro-dynamic action in the forms of magnetic attraction, repulsion, and polarity, our observations have been principally confined to noticing the impulses exerted between the *polar* parts of such bodies. In describing the reciprocal action between portions of matter serving as the pathways of electric currents, two distinct relative electro-static conditions were shown to be the result, viz., a natural *polar* arrangement, where the currents circulating about the poles or axes of two bodies are arranged facing each other, as when the dipping-needle becomes arranged vertically at the magnetic pole of the earth, as exhibited at C; and an *equatorial* arrangement exhibited at A, in the same figure, where the currents circulating about the equatorial parts face each other, as occurs when the same magnetic needle is transported to the equatorial regions of the earth.

Fig. 125.



The first-named relative electro-dynamic action and reaction having been considered, it now remains to take a brief view of the reciprocal impulses developed between the latter class of relative directions of electric currents about the circumferences of atoms and masses.

This modification of the propagation of electro-dynamic impulses, we shall hereafter denominate "equatorial."

In describing the grouping of atoms into crystals, reference has been previously made to this reciprocal action between the equatorial parts of all molecular groupings of atoms at insensible distances, as exhibiting a comparatively feebler intensity of development of attractive force than between the polar parts, as tested by the flaking or cleavage of the atoms from the faces of crystals. This equatorial development of electro-dynamic impulses between the surfaces of approximated bodies being comparatively feeble, the investigation of them is involved in more obscurity than that of the polar development. Indeed, the discovery has recently excited great interest among scientific men.

In relation to this subject Professor Faraday has disclosed he following instructive facts, which he has published in the 8th number of the Philosophical Magazine, page 147.

He suspended a bar of glass, two inches in length and half n inch in width and thickness, by a long thread composed of everal fibres of silk cocoon, attached to the centre of the bar, as to permit it to turn freely in a horizontal direction. The vo poles of a powerful electro-magnet were placed on each side f the glass bar, the centre of it being arranged in a line between e poles, which he terms the line of magnetic force. Previusly to the establishment of the magnetic action, if the position f the bar be such that its axis is inclined at half a right angle that line, then, on completing the circuit of the battery nd bringing the magnetic power into operation, the bar will ecome turned so as to take a position at right angles to the me line, and will continually be impelled to return to that osition. A bar of bismuth exhibits this effect of the action of agnetic forces; but if a bar of iron, which is familiarly known be more readily acted upon by magnets than glass or bisuth, be substituted in place of these substances, it will become rned, so as to present its two ends in a line extended beveen the two poles of the horseshoe magnet, and consequently a line of direction at right angles to that of the position taken y the bar of glass and of bismuth whilst subjected to the same fluence.

This experiment of Professor Faraday demonstrates the fact at exactly transverse impulses of mechanical force are imparted different kinds of substances, whilst placed within the influence f magnetic forces, which exhibit two different classes of pheomena, designated by Mr. Faraday under the distinct heads of rdinary magnetic action, such as is presented in the phenomena f the movements of iron produced by magnets; and of the exaordinary opposite direction of action, as illustrated in the preeding experiment.

To distinguish these opposite directions of the action of magetic forces on different kinds of substances, Faraday has arnged them into two classes, which he has designated by the rms "*Magnetics* and *Dia-magnetics.*"

These opposite effects are simultaneously exhibited when iron filings are sprinkled on a piece of white paper resting on the pole of a horseshoe magnet. On gently tapping the paper with the finger, the particles become arranged transversely into peculiar lines, indicating "magnetic curves." If bismuth, reduced to a very fine powder, be substituted in place of the iron filings, the particles are found to become arranged in the "dia-magnetic" lines or curves, in contradistinction to the ordinary *magnetic* curves, which are every where intersected at right angles by the lines of these dia-magnetic curves.

Professor Faraday examined a great variety of simple and compound substances in solid, liquid, and gaseous states, for the purpose of ascertaining their respective places, as tested by the relative electro-mechanical *axial* and *equatorial* currents constituting the division of such substances into the *magnetic* and *dia-magnetic* classes. He states that he found the number of simple bodies, which belong to the class of magnetics, to be extremely limited, consisting only of the metals iron, nickel, manganese, chromium, cerium, titanium, palladium, platinum, and osmium. All other substances, whether in solid or liquid states, are *dia-magnetic;* that is, they are acted upon by electro-mechanical forces in obedience to the same law which governs the movements of the metal bismuth, as above described.

The intensity of the electro-mechanical forces he found to vary in increasing degrees in different kinds of dia-magnetic substances, from arsenic, which exhibits the feeblest indications of possessing this property, to bismuth, which exhibits the most powerful indications of the same property. The order of several substances, exhibiting this increasing scale, he has presented in the following list: arsenic, ether, alcohol, gold, mercury, flint-glass, tin, lead, zinc, antimony, phosphorus, bismuth.

Having failed in every attempt to discover magnetic forces in action in connection with gaseous bodies, Professor Faraday considered all gases as occupying the neutral point in the magnetic scale, intermediate between magnetic and dia-magnetic bodies.

He found that the magnetic properties of compound bodies depend on those of their preponderating component elements. Thus the particles of magnetic iron retain their electro-mechanical forces when combined with other particles of the dia-magnetic class of substances, the two forces acting in opposition to one another, and the resulting effect being only that due to the difference in their power. Hence the salts of iron exhibit the action of magnetic forces whilst held in solution in water, when the particles are brought within the sphere of the influence of these forces by their approximation during the evaporation of the water, which in large quantities serves to remove them asunder beyond this influence. Hence it appears that saline solutions, when made of various degrees of strength, may serve as actual tests of the action of the relative degrees both of the polar and equatorial, or *magnetic* and *dia-magnetic* forces, developed in connection with different bodies, whether solid or fluid; but more especially in the latter: as the particles when under examination in a fluid state admit of being suspended or diffused in other liquids, wherein the equatorial or polar forces become manifest either by the repulsive forces apparent in the dissolving of the solid crystals of the salt in the fluid, or by the aggregation of the dissolved particles into solid crystals.

The preceding facts have been supposed to be resolvable into this simple general law, "that while every particle of a *magnetic* body is attracted, every particle of a *dia-magnetic* body is repelled by either pole of a magnet; which opposite attractive and repellant forces continue in action as long as the exciting magnet is held near the bodies excited thereby."

On this development of dia-magnetic and magnetic forces, which we have considered as polar and equatorial actions, may rationally be founded calculations of the expansive force of steam, and the solution in water of solid crystals of salts and even of quartz rocks, and the reuniting of them to re-compose such solid crystals on the evaporation of the solvent fluid medium.

Professor Oersted has recently published the results of some of his researches on dia-magnetism; of which the following is an abstract.*

" My researches relate to the celebrated discoveries of Faraday, and to the developments which these have received from the German philosophers.

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* Silliman's Journal, p. 233, March, 1849.

"Faraday encountered in his experiments with his great electro-magnet, a class of bodies which are repelled by the two poles of the magnet. This repulsion had been for a long time well known in the case of two or three substances; but the researches of the illustrious English philosopher have given to this fact a generality and an importance which has rendered it an attractive subject to all men of science.

"Weber demonstrated that dia-magnetic bodies receive, by the influence of an electro-magnet, a transversal magnetism, having two poles so disposed, that each of them has the same sort of magnetism as the nearest pole of the electro-magnet. These are the labors which served as a starting point for my researches."

In performing his experiments Oersted used a large U electro-magnet, capable of supporting about 3,000 lbs.; and the bodies subjected to the dia-magnetic action were suspended between the two poles; between which they are allowed to oscillate in obedience to the dia-magnetic impulses. The experiments were made with many dia-magnetic bodies, such as bismuth, amber, alabaster, tortoise-shell, quills, sulphur, pit coal, &c., reduced to the forms of rectangular needles.

When the dia-magnetic needle is suspended between the two poles of an electro-magnet in accordance with the experiments already cited, it exhibits the magnetic poles in a transverse direction, disposed in such a manner that the magnetism of each side is of the same nature as that of the nearest pole of the electro-magnet.

Oersted found that there exists an opposition of magnetism in the two halves of each edge taken separately; and also in each half between the two edges, the upper and lower. He observes: "We have hitherto known only the dia-magnetic effects in bodies which are repelled by the electro-magnet. My experiments have shown that a similar effect is produced in most bodies which are attracted by the two magnetic poles; and these constitute a new species of dia-magnetic bodies. We therefore distinguish two classes, *repelling* and *attracting* dia-magnetic bodies."

"A needle made of a body capable of being attracted by the magnet, but of which the magnetism is not of the same nature as at of iron or nickel, suspended between the two polar forces of e electro-magnet, is known to take the position called by Pro-ssor Faraday *axial;* but if made to rise above the upper edges r to descend below the lower edges of the polar faces, it takes n equatorial position."

These details of Oersted's experiments appear to prove con-lusively that all "dia-magnetic" phenomena are traceable to the ction and reaction between equatorial currents about the axes f portions of matter. His statement "that there exists an oppo-ition of magnetism in the two halves of each edge, taken sepa-ately, and also in each half between the two edges, the upper nd the lower," gives a result which is theoretically to be antici-ated from the oppositely directed movements of electric cur-ents, about the two opposite sides of bodies arranged longitu-inally between the tops of the two poles of an U magnet.

To test the intensity of Magnetic forces exerted on magnetic eedles recourse is had to Coulomb's Torsional Balance, and also o counting the number of oscillations made in a given time. The more intense the action, the more rapidly are the oscilla-ions made. It was by this method that Humboldt ascertained the law of increase of magnetic forces from the equator to the poles. The same needle which had made 245 oscillations in 10 minutes in Paris, made only 229 at Cumana, in 10° 29′ north latitude, and only 211 under the magnetic equator.

ELECTRO-MAGNETISM.

The knowledge of the modes of excitation of the phenomenon f Magnetism, by means of Electricity, constitutes the new ranch of science denominated Electro-Magnetism.

Numerous instances have been long ago recorded, in which ightning had imparted magnetic properties to pieces of steel. In one case, where lightning had passed through a box filled with steel knives, several of them were discovered to be partially melted, and others were found capable of attracting and suspending nails and other pieces of iron.

An instance had also occurred where the poles of a compass-needle became actually reversed on board of a vessel struck by lightning near Cape Cod;—an accident which was not discovered until the ensuing night, when it was noticed that the * marked pole of the needle pointed from the polar star, thus disclosing to the mariners that they were steering their vessel in an exactly opposite direction to their intended course.

Whenever the attempt was made to produce similar changes of the polarity of needles, by discharges from Leyden jars, sometimes one end or pole of the steel needles, and sometimes the other, exhibited the * polarity. So many anomalous irregularities attended these experiments, that they even tended to throw a shade of doubt over the whole science of Electro-dynamics, as being founded on the action of a capricious agency of nature, governed by no determinate laws. This fact has been referred to in treating of secondary, tertiary, and subordinate currents, induced in approximated bodies, by electric discharges. The sudden and fitful explosive discharges of Leyden batteries, like the lightning's dazzling glare on a region shrouded in darkness, served to bewilder the original explorers of this field of science.

Beccaria discovered, in the year 1777, that a needle, through which he had sent an electric shock, had acquired "a curious species of polarity; for instead of turning, as usual, to the north and south, it assumed a position at right angles to this direction, its two ends pointing to the east and west." As has been noticed, there is little doubt, that if he had followed up the inquiry which this important fact had opened to him, he could soon have arrived at the great discovery which was made about half a century afterwards by Oersted, whereby this mystery has been dispelled.

After Volta's discovery of a mode of exciting a continuous and milder mode of propagating electric action, experimenters slowly began to test the powers of this new kind of electrical apparatus, in producing magnetic effects.

In 1807, Ritter published an account of his having succeeded in imparting to a louis d'or the properties of a negative and positive electric pole, by contact with the extremities of a galvanic circuit, and obscurely intimated the discovery of electric poles, at right angles to adjacent magnetic poles.

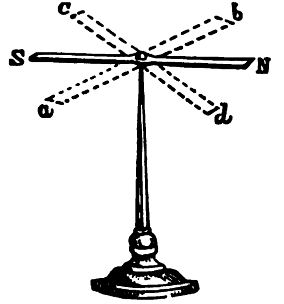
During the course of innumerable experiments which were made, and of the consequent arguments and theories which were adduced, some of the experimenters appear to have advanced to the very threshold of the wonderful discoveries subsequently made by Oersted, Ampère, and others. As remarked by P. M. Roget, "it is still curious to notice by what devious paths they were led away from the truth, at the moment when they had nearly reached it, and when a very slight variation in the form of their experiments would at once have disclosed it to their view." In a retrospective view of the discovery of this simple fact, constituting the origin of the science of electro-magnetism, it seems incredible that accident should not have previously unveiled it to the notice of some one of the hundreds of experimenters who had been engaged in using magnetic needles in proximity to conducting wires. And more particularly is this surprise increased, when we consider that Oersted published in 1807, a work, in which he announced his intention of "verifying the fact, whether electricity, in its most latent state, exerted no action upon the magnetic needle." About the year 1813, Oersted also published a work on the Identity of Chemical and Electrical Forces, in which he pointed out the probable relationship between the electric and magnetic fluids; which he supposed might differ from one another only in their respective degrees of tension. The discovery of the above-stated important fact, which has immortalized his name, was not actually made until six years afterwards, in the year 1819. Thus dilatorily was established the very basis of the science of the action and reaction of electricity in motion in the form of currents.

The following account is the first notice which Oersted published announcing his successful experiment.

"The two poles of a powerful galvanic battery were connected by a metallic wire, so as to complete the galvanic circuit. Then taking a magnetic needle, properly balanced on its pivot, and allowing it to assume its natural north and south direction, I placed a straight portion of the uniting wire horizontally above the needle, and in a direction parallel to it; and then completed the circuit, so that the electric current passed through the wire.

"The moment this was done *the needle changed its position*, its ends deviating from the north and south toward the east and west; and it remained stationary in a position across the wire.

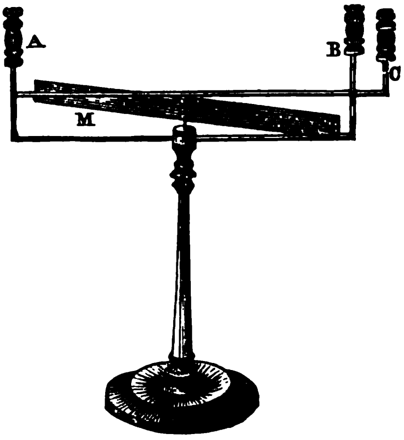
Fig. 126.



By reversing the direction of the electric currents, he discovered that the N or * pole became turned about from its usual north and south position, as represented in the figure, where W R represents a conducting wire arranged above the needle. The needle becomes deflected from its natural position, to that indicated by the dotted lines *c d*, or *a b*, according to the direction of the current from W to R, or reversely from R to W.

The relative movements of the needle produced by variously directed electric currents above and beneath the needle, to demonstrate Oersted's experiment, are commonly exhibited by the instrument represented in the annexed cut, where M is the magnetic needle, and A B C connecting cups. The conducting wires, B and C, are not in contact at their point of intersection, but are soldered together at their junction at A.

Fig. 127.



By means of this instrument the galvanic action may be propagated above and beneath the needle in similar and opposite directions, at pleasure.

When the action is propagated from A to B *beneath* the needle, it is turned toward the right hand of the spectator who regards the movement whilst facing the * pole. If the current be reversed from B to A, a reversed movement is produced; as is also the case when the current is propagated *above* the needle instead of beneath it; but by propagating the action in the direction from B to A, beneath the needle, and from A to C above it in a returning circuit, they both combine to augment the action. Nor are the vertical portions of the current descending from B and ascending toward A to be neglected, for they also conspire to develope an important action, as has been illustrated by figure 35, page 239. The principles of the reciprocal electro-dynamic actions of electric and magnetic currents have been theoretically illustrated at page 228, figure 26, and page 240, figure 36.

The succeeding year after Oersted's interesting discovery, (1820,) Ampère commenced a system of physical and theoretical researches for developing both the impulses of mechanical force, brought into action by the various relative movements of approximated electric currents, and the theoretical principles governing their actions. In his illustrations of the various complex movements of a magnetic needle when held near the conducting wire connecting the poles of an excited battery, he introduced one of those happy illustrations, which, for its utility, is likely to be perpetuated in the recollections of every student of the science of Electro-dynamics.

To enable the observer to decide at once which way the * pole of the needle will become turned by the influence of an approximated electric current, he recommended that such observer should consider himself as extended along the circuit of the conducting wire, with the positive current entering at his feet and passing out at his head, and with his face fronting the needle. The * pole will become turned towards the left side.

He described several instruments, particularly spiral coils of conducting wires, denominated "Electro-dynamic Cylinders," which he announced would exhibit identically the same phenomena of attraction and repulsion as regular magnets. He also described the construction of the new familiar apparatus of a galvanic "helix."*

In extending the application of the action of galvanic currents to other bodies than steel magnetic needles, Arago discovered, about the same time, that iron filings were attracted by conducting wires (figure 40, page 246), and Professor Moll of

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* For the details of these communications the reader is referred to the Annales de Chimie, vol. xv., pages 59 to 170.

Utrecht extended this principle of excitation by environing a bar of iron by the spiral coils of the conducting wire. The fact of the excitation of magnetic action by galvanic electricity being thus brought to light, it became an object of interest to ascertain to what degree of intensity the mechanical action or Natural Motive Power of magnets formed by electricity could be rendered available. To determine practically this question, Professor Henry and Dr. Ten Eyck made the following experiments in Albany, New-York.*

The details of these interesting experiments afford so much instructive information in the science of Electro-dynamics, that the history of them becomes a profitable study:—

"A round piece of iron, ¼ of an inch in diameter, was bent into the usual form of a horseshoe; and instead of loosely curling around it a few feet of wire, as is usually described, it was tightly wound with 35 feet of wire, coated with silk, so as to form about 400 turns; a pair of small galvanic plates, of only 2½ square inches of surface, which could be dipped into a tumbler of diluted acid, was soldered to the ends of the wire, and the whole mounted on a stand. With these small plates the horseshoe became much more powerfully magnetic than another of the same size wound in the usual manner, even by the application of a battery composed of 28 plates of copper and zinc, each 8 inches square."

This experiment served to demonstrate, that by increasing the number of coils of the wire, and by more carefully winding and insulating them, a galvanic battery of $\frac{1}{600}$th part of the size of those previously used became adequate to exciting equally intense impulses of Electro-mechanical force.

By substituting a larger bar of soft iron, ½ of an inch in diameter instead of a ¼ of an inch, of the same horseshoe form, a still heavier weight of 14 lbs. was lifted by the electro-mechanical force thus developed.

"A second conducting wire, of the same length as the first, was wound over the same bar of iron used in the preceding experiment, and the ends soldered to the zinc and copper in such a manner, that the galvanic current might circulate in the same direction in both, or, in other words, that the two wires might act as one; the effect by this addition was doubled, as the horseshoe, with the same plates before used, now supported 28 lbs.; thus demonstrating, that by doubling the extent of the circulating current the electro-mechanical force brought into action was also doubled.

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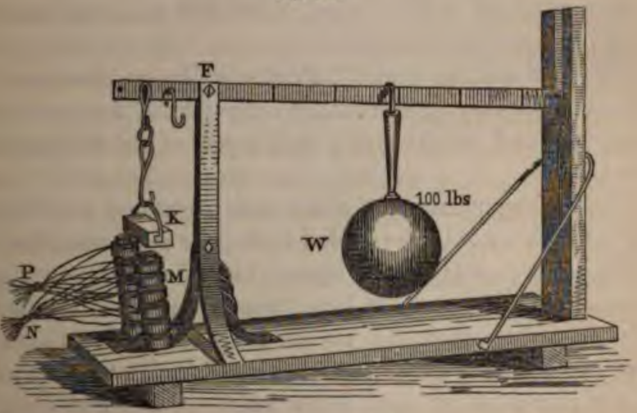
* Silliman's Journal for 1831, page 408, and April, 1832.

"In order to test on a larger scale the truth of these preliminary results, a bar of soft iron, two inches square, and twenty inches long, was bent into the form of a horseshoe, nine and a half inches high, and weighing twenty-one pounds, around which five hundred and forty feet of copper bell-wire were wound in nine coils each of sixty feet, and each occupying about two inches of the horseshoe, according to the principle before mentioned. The several ends of the wires were left projecting and all numbered, so that the first and last end of each strand might be readily distinguished. In this manner was formed an experimental electro-magnet on a large scale, with which several combinations of wires could be made by merely uniting the projecting ends. This arrangement is exhibited in the annexed figure. By soldering the last end of the first wire to the first end of the next wire, and so on throughout all the series, the whole five hundred and forty feet admitted of being connected into one continuous coil of long wire; and by disconnecting them, any of the series might be successively experimented upon. An iron bar was fixed above the magnet, so as to act as a lever beam of a com-

Fig. 128.



mon steelyard, on which the weight was moved out toward the extreme end to determine the force exerted by the magnet. The battery employed consisted of two concentric copper cylinders, with a zinc cylinder between them, of the whole extent of both of the surfaces of the zinc.

"*Experiment* 1. When the battery current was transmitted through each one of the sections of wire coil, of 60 feet in length, the magnetism developed by each was found to be just sufficient to lift the armature, which weighed 7 pounds.

"*Experiment* 2. When transmitted through two of the sectional coils, one arranged on each leg of the horseshoe, the weight lifted was 145 pounds.

"*Experiment* 3. When transmitted through three sectional coils, including one coil arranged on the middle of the arch, the weight lifted was 300 pounds.

"*Experiment* 4. When transmitted through four sectional coils, two in each leg, the weight lifted was 500 pounds.

"*Experiment* 5. When transmitted through six coils, the weight supported was 570 pounds.

"*Experiment* 6. When transmitted simultaneously through all the nine sectional coils of wire, of 60 feet each, the maximum weight lifted was 650 pounds!"

"This astonishing result," Professor Henry observes, "was produced by a battery containing only $\frac{2}{5}$ths of a square foot of zinc surface, and requiring only half a pint of diluted acid for its submersion."

When a larger battery, formed with a plate of zinc 12 inches long by 6 inches wide, surrounded by copper wire, was substituted for the battery of $\frac{2}{5}$ths of a square foot of surface, used in the last experiment, the weight lifted was 750 pounds. This effect, Professor Henry supposes to be the maximum of magnetic power which can be developed in this piece of iron; for the effect was not increased by applying a large calorimotor containing 28 plates of copper and zinc, each 8 inches square.

"This result is by no means the maximum which can be produced by a small galvanic battery; as in every experiment we have made, the power increases by *increasing the quantity of iron;* with a bar of iron, similar to the one used in these experiments, but of double the diameter, or of eight times the weight, the power would undoubtedly be quadrupled, and that too without increasing the size of the galvanic battery."

By increasing the size of the bar of iron used for magnets, and the number of circuits, the armature was caused to sustain a weight of about a ton. An electro-magnet, constructed by Professor Henry, at Princeton College, New Jersey, has rendered manifest a still more surprising development of electro-mechanical force. He made use of a massive bar of round iron, of the diameter of nearly four inches, and weighing about 100 pounds, bended to the usual form of a U magnet. Around this bar was wound 30 distinct strands of properly coated copper bell-wire, each strand being about 40 feet long, and serving as a distinct channel for the transmission of the electricity excited from a small battery of 22 pairs of zinc and copper plates, each of the dimensions of 9 × 12 inches, and arranged on Dr. Hare's plan of a "calorimotor," so that all the zinc plates being united together by wires, and all of the copper plates being similarly united, are caused to act like one great sheet of copper and one of zinc.

With this electro-magnet he succeeded in exciting sufficiently intense impulses of electro-magnetic force to lift a weight of 3,500 pounds.

Immediately after the announcement of this discovery of the great intensity of mechanical power producible by means of electro-magnets, public attention was awakened to the subject of rendering this extraordinary power available for practical purposes. Consequently numerous projects were specially undertaken for constructing electro-magnetic engines for using this newly-discovered electrical action as a substitute for steam power. These enterprises, in which great ingenuity has been exercised, and an almost infinite variety of costly experiments have been made, will presently be noticed in a distinct chapter, appropriated to the consideration of electro-magnetism as a source of natural motive power.

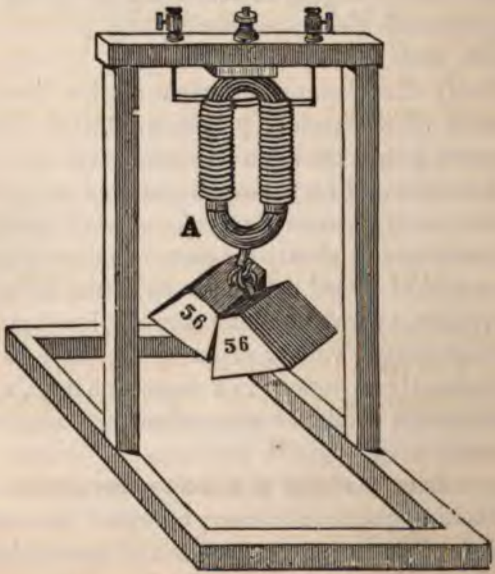
In experiments made to determine the extent of distance from the exciting galvanic battery, at which the coil could be successfully used to develope impulses of mechanical force on the armature of an electro-magnet, Professor Henry ascertained that "the current from a galvanic trough is capable of producing about as great an effect on soft iron after traversing more than

$\frac{1}{5}$th of a mile of intervening wire, as when it passes only through the wire surrounding the magnet."

It appears that Mr. Barlow, in England, had previously suggested the use of this principle of electro-magnetic action for operating an *electro-magnetic telegraph*, but failed in his experimental trials from inability to transmit the galvanic current to act at a remote distance from his battery, composed of a single pair of plates. In allusion to this cause of failure, Professor Henry suggested "this fact, that the magnetic action of a current from a trough (or combination of several pairs of plates) does not become sensibly diminished by passing through a long wire, is directly applicable to Mr. Barlow's project of forming an electro-magnetic telegraph."

This discovery, and the suggestion accompanying it, was seized upon by Professor Morse for the purpose of accomplishing practically a plan of an electro-magnetic telegraph, as will be hereafter narrated in detail.

Fig. 129.



The maximum lifting power of an electro-magnet, as compared with the weight of iron used for the magnet, appears to have been exhibited by Dr. Ten Eyck, of Albany. This was a small electro-magnet weighing only 6 grains, and surrounded by 3 feet of wire, excited by a small battery, whereby 420 times the weight of the bar-magnet itself was sustained.

Instead of shaping the bar of iron to the horseshoe form, whereby only the two contracted ends or poles are presented to act together, Mr. J. P. Joule has contrived to shape the iron into two flattened rings of a foot in diameter, which are applied together laterally, and consequently with a much greater relative extent of surface of the parts subjected to the electro-dynamic action. Two such circular iron rings weighing less than twelve pounds, whilst thus electro-dynamically excited, required a divellent force equal to that of a weight of 2710 pounds to separate them, whereby 225 times the weight of the magnet was sustained.

The preceding remarkable experiments prove that the temporary magnetic force induced by means of electricity, far transcends in power that of natural or artificial permanent magnets. The famous artificial steel magnet in Haerlem, in Holland, which was once exhibited to me by one of the professors there as being the greatest philosophical curiosity in that ancient city, renowned in the annals of science, was capable of actually suspending by the armature a weight of only 200 pounds.

LAWS OF ELECTRO-MAGNETIC ACTION.

The electro-motive power developed by means of coils of conducting wire encircling bars of iron and steel, has been reduced by Professor Jacobi, to the following laws of action.

Laws of Action of Electro-motive Forces.

1. The amount of magnetism induced in a bar of soft iron by the circulation about it of a current of electricity from a galvanic battery, is proportional to the force of the current.
2. The total extent of the action of the current circulating

around a bar of iron in the coils of a helix, is equal to the sum of the effects produced by each coil separately.

3. When the diameter of the iron cylinder forming the central coil of the helix is surrounded, the length remaining the same, the force of magnetism developed by a given current, is increased in the same ratio. The variations of the length of the iron coil only influences the result by admitting the use of a greater number of turns of the helix upon it.

4. The attraction of electro-magnets is proportional to the square of the force of the galvanic current, which induces the development of the magnetic impulses.

MECHANICAL FORCE OF COHESION AND OF CHEMICAL AFFINITY.

" There are Agents in Nature capable of causing the particles of matter to stick together by very strong Attractions; and it is the business of Experimental Philosophy to find them out."—NEWTON.—*3d Book Optics.*

IN tracing to an original source the cause of Natural Motive Power, we have now advanced to a barrier, which must either yield to our efforts, or arrest our further progress. We have arrived at that frontier of the regions of Physical Science, which is preoccupied by able defenders who are intrenched behind long established popular theories and doctrines of "INHERENT FORCES" and "INNATE POWERS," as constituting the true causes of the motion and rest of matter.

When the exploring traveller is about to attempt to trace out the course of some powerful river to its originating source by following its windings amid bewildering thickets and frowning mountains, through which he must necessarily make his way in order finally to win a glance at the pure and sparkling fountain from which it is poured forth, he warily examines the best charts possessed by the ancient occupants of the vale he is to traverse. These he may follow or diverge from, as they prove truthful or not.

Before advancing further in tracing out the cause of the Natural Motive Power which controls the states of motion and rest of terrestrial matter, it will be profitable to take a similar preliminary view of the charts which the present state of human knowledge furnishes in relation to the object of our pursuit.

So familiarized have mankind become with the grouping of atoms of elementary substances into various solidly fixed arrangements, constituting the Inorganic and Organic Formations, which have been synthetically classified and examined in the preceding pages, that they have not only popularly, but even scientifically, considered the causes of these groupings, as inherent self-originating and self-directing powers.

In scientific works, Cohesion has commonly been defined to be "an *inherent* force of natural attraction, causing the constituent particles of bodies to unite in a mass."

The preceding definition conveys the idea of the existence of a self-acting cause of mechanical impulses, to which the name of "ATTRACTION" has been given.

In the earliest edition of Newton's great work, entitled the "Principia," or Principles of Natural Science, the illustrious philosopher advanced the doctrine that "*the ultimate particles of bodies are endued with* INHERENT FORCES *or* POWERS *of attraction and repulsion.*" In his later writings, Newton has expressly stated in regard to Gravitation, that he could not conceive the gravitating matter, of which the planets are composed, could be held together by virtue of *inherent powers*, or *innate forces.*

Adopting the original opinion of Newton, philosophers have subsequently persevered in maintaining the doctrine of "Inherent Powers" or "Innate Forces," in disregard of his later opinions. The youthful scholar, in reading the narration of the important discovery of the Laws of Gravitation as originating from the accidental notice of the fall of an apple from a tree, is still taught to ascribe that phenomenon to an *innate* or *inherent* tendency in all matter to descend toward the centre of the earth with a velocity increasing regularly at the rate of $16\frac{1}{12}$ feet during each second of its fall. This fact is truthful; and the laws founded thereon may be classified among the most sublime discoveries of human sagacity. But to affirm positively that the cause of the impulses of mechanical force producing the effect of the movement of the apple toward the centre of the earth originates from a cause inherent in all matter, is the assumption of an unproved fact, which can have no other object than the concealment of ignorance. It is therefore pedantry to assume the existence of a fact, until we know it to be true.

In his "Outlines of Astronomy," Sir John Herschel observes, "all bodies with which we are acquainted, when raised into the air and quietly abandoned, descend to the earth's surface in lines perpendicular to it. They are therefore urged thereto by a force or effect, which it is but reasonable to regard as the direct or indirect result of a consciousness, and a will existing *somewhere*, though beyond our power to trace, which force we term *gravity*, and whose tendency, or direction, is towards the earth's centre."

That the phenomenon of the movement of bodies toward the centre of the earth is the "direct or indirect" result of a will existing "somewhere," is unquestionably a philosophical truth; but whether this be a result of the direct will of the Creator, or of the indirect will of the Creator, through established laws of the propagation of impulses of mechanical force, is the business of experimental philosophy to find out.

In explaining the cause of the impulses of mechanical force producing the grouping of atoms at insensible distances, as denoted by the popular terms "Cohesion," and "Chemical Affinity," Professor Graham, of the London University, affirms that "*combination* appears to be the natural condition of matter,—the source of its *cohesion*, and *aggregation;* which it retains by *inertia*."

This explanation increases the perplexity of the student, by referring the source of "cohesion" to another agency of nature, which the Professor terms "combination;" and leaves him again pertinaciously to inquire, What is the cause of "combination?"

To this question Dr. Turner has replied in his very popular treatise on Chemistry, which serves as a text-book in colleges and schools, "Diversity of nature appears to be the reason why bodies combine." This reply still prompts another inquiry, Why is "diversity of nature" considered as a cause of the mechanical effect of the combination of bodies?"

Again, Professor Graham states that the "particles of a body in the solid or liquid state, exhibit an attraction for each other, which is the force of cohesion." He continues, "*Adhesion* retains bodies in contact, which are once placed in sufficient proximity to each other, as exhibited in the adhesion of two smooth pieces of lead, &c."

"But this kind of attraction is deficient in a character which is never absent in true *chemical affinity;*—it effects no change in the properties of bodies. It may bind different kinds of matter together, but it does not alter their nature."

Dr. Turner affirms, "Affinity is exerted between the minutest particles of different kinds of matter, causing them to combine so as to form new bodies endowed with new properties. It acts only at insensible distances."

In the 6th American edition of Dr. Turner's Chemistry, the very intelligent editor, Dr. Bache, remarks, in an explanatory note, "It should be borne in mind that the force, which tends to bring the elementary molecules of matter into closer proximity, is derived from an *innate property* of ponderable matter."

A very extraordinary inference follows from the admission of the doctrine of the existence of absolute innate causes of motive power in lifeless matter; for it carries with it the idea of the endowment of the matter of the planets with a degree of innate intelligence to know the direction of the location of each other's centres. The plumb used by masons and carpenters unfailingly points toward the centre of the earth, as well during the darkness of midnight, as during the light of mid-day. The most intelligent mechanics and engineers are daily to be seen deferentially submitting to this superior sagacity of a lump of lead, or of some liquid in the spirit-level.

Inspired with gratitude and admiration by regarding the apparently sagacious movements of his compass needle, the superstitious mariner might still be led to imagine, during the tedious protracted hours of his watching, throughout gloomy nights, the faithful movement of its ever-turning pole, that he actually beholds the guiding finger of an intelligent friend. Had it not been recently discovered that these once mysterious movements are now practically producible by every schoolboy in the lecture-room, by means of a piece of common wire connecting two tiny sheets of copper and zinc, floated by a chip of cork on a basin of water, the sailor might still have had reason to imagine, like the Greek philosopher of old, that his compass needle has a soul, or innate intelligence.

By summarily ascribing impulses of mechanical force which "bring the elementary molecules of matter into closer proxi- [illegible] to an *innate property* of ponderable matter," all inquiry [illegible] source or cause of the mechanical forces of cohesion, and of chemical affinity is abruptly cut off, although "Affinity is the basis on which the science of chemistry is founded," as Dr. Turner affirms—(8th edition of Turner's Chemistry, published by Liebig and Gregory, page 130.)

The assumption of dogmas of "innate" and "inherent" forces in all atoms of matter so directly clashes with the law of mechanical science establishing the passiveness of lifeless matter, and its inability "to move itself when in a state of rest," that the two sciences of Chemistry and Mechanics are thus brought into collision upon this special issue, in which it must finally be decided that the one or the other is erroneous.

The preceding extracts from two of the most recent popular works on Chemistry, written by eminent European chemists, and used as text-books in the United States, serve to prove the truth of Mr. Dana's remark, that "from the account of *Cohesive Attraction* in works on Chemistry, we gather little more than what the term itself implies." (Silliman's Journal, Nov. 1847.)

And so also in regard to the orginating cause of the movements of matter constituting the phenomena of Gravitation, Professor Robison observes, that "philosophers cannot explain it in any other way than by calling it *a property of matter;* and this is acknowledged to be no explanation at all. (Robison's Philosophy, page 210.)

Every attempt to conceal ignorance of physical truths under affirmations of the existence of supposititious agencies of Nature, and under a blending of confused ideas of causes and effects, such as are embraced in the scientific terms used to denote Heat, Light, Cohesion, Gravitation, &c., derogates from the true dignity of Science, and serves to impede, rather than to advance its progress, by precluding further inquiries and investigations, in pursuing discoveries of the physical causes of Natural Motive Power.

When "the causes of things" could not be rationally explained, it was once common to ascribe them directly to their "Nature," as the ascent of water in suction pumps was once ascribed to the "abhorrence of Nature to a vacuum."

This general "abhorrence" was necessarily reduced to a special abhorrence, as before noticed, when it was afterwards discovered that the water would rise only to a specific number of feet and inches of perpendicular height. And so the expansion of the molecules of the same water, to occupy 1700 fold more space, in the form of steam, to the exclusion of the atmosphere therefrom, and against a continual pressure, measured by 15 lbs. to the square inch, is still similarly ascribed to a special "Imponderable Agent" of Nature, named "Heat." This agent of nature has actually a special inclination in favor of a vacuum, ascertainable by a scale of feet and inches of space, and of pounds and ounces of mechanical pressure.

To account for the resistance to separation of the atoms of a bar of iron, on the other hand, as for the facility of the separation of the molecules of water in the preceding case, still another "Agent" is called into requisition, named "Cohesion;" which is found also to be similarly endowed with a special abhorrence to a separation of the atoms of the bar of iron, until the divellent force applied acquires the intensity of about 60,000 pounds to the square inch. This special abhorrence becomes doubled to 120,000 pounds to the square inch by introducing about 2 atoms of carbon to 98 atoms of iron, in the process of converting it into steel.

Visionary as have been commonly considered some of the speculations advanced by the celebrated Bishop Berkeley, yet his practical views of the philosophy of the Science of Mechanics appear to have been in advance of those of the philosophers who have preceded, and succeeded him. His opinion of the true nature of the state of rest and motion produced by molecular forces truly appears to be fraught with admirable exactness of conception. He affirms that "in reality, the minute particles of matter are only agitated, according to certain laws of nature, by some other agent, wherein the force exists, and *not in them*, which have only the motion;" concluding that "*nothing mechanical can be a cause.*"

The latter sentence merits to be enrolled as the sublimest law of Mechanical Philosophy; for it ascribes the original cause of the movement of all inert matter to God, and not to the "inherent properties" of such matter, as is popularly taught at the present day.

Bacon manifested a sense of the impropriety of this ascription of inherent forces developed between atoms at insensible distances, by classifying all terrestrial matter into two kinds, which he denominated "active" and "passive." This, although only a half-way step, was an important advance in mechanical philosophy.

The preceding extracts are sufficient to show the unsettled state of the present popular doctrines adopted for explaining the mechanical effect of the groupings of atoms at insensible distances in solid aggregations, constituting the phenomena of Cohesion and Chemical Affinity. This review also shows the necessity of dissipating old errors, by supplanting them with more exact explanations.

As the Newtonian system of mechanical philosophy is founded on the certain fact of the tendency of all masses of matter to move towards each other's centres, and as its truthfulness has been established by the most perfect mathematical demonstrations, it can never be affected by the establishment of the actual existence of any cause of natural motive power adequate to producing identically the same results as those hypothetically ascribed to "inherent properties" of matter. On the contrary, these sublime laws or principles of the action of impulses of mechanical force exerted between the heavenly bodies, will become corroborated thereby.

THE PHENOMENON OF "COHESION" CONSIDERED AS ORIGINATING FROM THE CONTINUOUS PROPAGATION OF THE ELECTRO-DYNAMIC ACTION OF THE SUN.

In treating of terrestrial electric currents, (page 252,) it has been demonstrated that they must necessarily induce a propagation of electro-dynamic action about all atoms, as well as masses of terrestrial matter; and that the very aggregation of atoms into masses, sufficiently large to constitute visible magnitudes, has been repeatedly illustrated in the synthetical investigations of the groupings of atoms into inorganic and organic formations. All the molecular forces developed between atoms at insensible distances have been traced to an universal system of polarization of terrestrial matter, produced and continuously sustained by the electro-dynamic action of the sun.

In treating of inorganic action, it has been shown that the direct electro-dynamic influence of the sun on the waters, covering a large portion of the surface of the earth, overpowers the polarization of the molecules, *indirectly* produced by the circulation of the terrestrial electric currents excited by the same cause. This direct polar excitation induces changes of polarizations of specific portions of such atoms, reducing them from their fixed *cohesive* state of groupings into crystalline arrangements, as from the state of cohesion of solid ice to the state of fluidity of water, and of the vapor of steamy thunder-clouds in the sky. On the cessation of this direct solar excitation, the same influence is indirectly propagated in the modified form of terrestrial electric currents, which produces the polarization of every atom of the whole orb, and speedily restores the atoms from such constrained electro-static conditions of polarization, to their natural polarization, as in water and ice.

The tendency of terrestrial polarization is to bring about crystalline arrangements of groupings of atoms into fixed states of aggregations, and to maintain them thus solidly grouped together by the continuously-sustained mechanical impulses, ascribed to cohesion. Every change from one electro-polarized state to another, developes mechanical action at sensible distances, as detailed throughout the preceding synthetical illustrations.

The effects of the grouping of atoms into symmetrically shaped crystals, have been detailed at page 86, and illustrated by figures 6 and 7. The cause of these mechanical effects as produced by the mechanical action of terrestrial electric currents, have also been shown at page 250, figure 45. The permanent circulation or establishment of electro-dynamic forces between atoms at insensible distances by their relative arrangements in the form of circles or closed circuits, constituting electro-dynamic rings, has been noticed at pages 248, 347, and 464, and represented by figures 44, 85, and 114. The aggregation of atoms in crystalline forms, is manifestly a mechanical effect of molecular action, similar to that of "cohesion," or identically the same.

"The phenomenon of crystallization is owing to the ascendency of cohesion over affinity," as affirmed by Dr. Turner, "crystalline form being independent of the chemical nature of the atoms, and determined only by their number and relative positions."

Assuming, then, that the terrestrial currents induced by the excitation of the sun on the surface of the earth, must serve to excite an infinite series of subordinate secondary currents in connection with every atom and mass of matter constituting the earth's surface, we may compare the impulses of electro-mechanical force excited reciprocally between the centres of bodies, with those which we have it in our power actually to exhibit by means of the floating rings of De La Rive, and of the electro-dynamic cylinders, which have been described in the preceding pages.

To constitute a *circuit* of polarized atoms, which has been shown to be necessary for sustaining a continuous static condition of an electro-dynamic ring, (figure 121, page 477,) there must necessarily be a grouping of at least four aggregated atoms, in order to permit their poles to become arranged at right angles. The cleavage of the successive laminæ of the surfaces of a crystal for the purpose of reducing it to its nucleus, may be supposed to take place from the equatorial sides of the atoms; whilst the more energetic polar action is maintained, causing the separated parts to peel off in entire scales or flakes.

As the polar action is more strongly developed than the equatorial action, the extension of the crystals first takes place in straight lines, as denoted by the "spiculæ." This fact may be noticed in every pool of freezing water. From the sides of these spiculæ, at various angles, other spiculæ shoot forth; and from these, still others. This obliquity of the arrangement of spiculæ may probably be ascribed to the inequality of the sizes of the atoms. The chemical equivalents of hydrogen and oxygen, combining to form molecules of water, being 1 to 8, there is reason to believe that there is equal disparity of their respective volumes.

When the electric currents, naturally circulating about the constituent atoms of a mass, are counteracted by intense artificially excited electric currents, or by the action producing the phenomenon of heat, both these equatorial and polar forces are overpowered, and the phenomena of crytallization, of solidity, chemical affinity, and cohesion, all simultaneously disappear.

That the development of the forces producing the phenomenon of crystallization originates from polarization of the freely movable atoms in the solutions of various salts, appears probable from the fact that the presence of solid bodies of already polarized groupings of atoms serves to determine the polarization and consequent clustering of the crystallizing particles. These facts may be shown by dissolving 3 pounds of crystallized sulphate of soda in 2 pounds of hot water, and by filtering the solution whilst hot, through coarse paper, to remove all foreign solid particles. If this solution be poured into a glass vessel, with a few drops of oil on its surface, and be set aside in a cool place, it may become perfectly cold without any appearance of the formation of solid crystals; and "even violent agitation may not cause the formation of crystals." But the presence of any solid body, such as the end of a wire, rod, or piece of thread, immersed in the solution, will immediately determine the polarization of the atoms, and the consequent commencement of the formation of crystals about the solid nucleus, from which they shoot out in all directions. It is thus common to crystallize sugar candy upon threads arranged in the form of baskets or other shapes, and immersed in syrup; and the most beautiful display of the crystals of alum and of other kinds of salts are thus artificially produced by the mere presence of some third kind of matter, which determines the polarity of the atoms of the solutions to specific arrangements.

The systematic movements of atoms during the process of crystallization has already been adverted to, as exhibited by the highly magnifying power of the solar microscope. A very interesting exhibition of these movements I have noticed by the naked eye during the formation of the beautiful crystals of the prussiate of potash (cyanide of potassium) in the process of the manufacture of this salt as an article of commerce.

Whilst the liquid is evaporating, the movements of the floating crystalline spiculæ are quite rapid about the strings, which are suspended in the liquor for the purpose of attracting them to become deposited thereon. The crystalline particles glittering in the sunlight, appear like insects endued with life, sporting about the strings, now approaching them, and then suddenly wheeling around them and receding, until finally they seem to alight thereon, in their beautifully symmetrical order of arrangement.

That the cause of the arrangement of atoms in crystals is electro-mechanical, is proved by the appearance of electric flashes during the process of the formation of various kinds of crystals, including even those of freezing water. This phenomenon of electric flashes is producible by suddenly dipping the finger into a highly saturated solution of several kinds of salts, after they have been suffered to become cooled in a very quiet place. When arsenious acid, dissolved in boiling hydrochloric acid, is left to cool in the dark, a *flash becomes distinctly perceptible on the formation of each crystal.*

So, in like manner, whenever the crystalline arrangements of atoms are disturbed by mechanically counteracting their cohesion, as by crushing the crystals of quartz, sugar, &c., in the dark, electric flashes become perceptible. According to a recent statement in the Edinburgh Journal, it appears that an experimenter has "found that flashes of light are distinctly produced by tearing a piece of cloth," and I have frequently observed similar flashes to occur when billets of wood are suddenly cleft asunder by an axe.

The most decisive proof that electrical action is the cause of the several phenomena of crystallization, is exhibited in the process of electro-metallurgy. In a letter to Professor Faraday, Plücker states, "Cyanite is by far the most interesting crystal I have examined. It points very well to the north *by the magnetic power of the earth only.* It is a true compass needle, and more than that, you may obtain its declinations." He further determined that there was some connection between the direction which cyanite assumes, and its cleavage planes.

In experimenting upon the crystalline polarity of bismuth and of other bodies, and on their relations to the magnetic force, Faraday states, that in preparing small cylinders of bismuth by casting them in glass tubes, he had often been embarrassed by the anomalous magnetic results which they gave. By experiments he found that the various crystals have their magnetic axes, and are moved by electro-mechanical impulses like magnetic needles, when subjected to the influence of approximated electro-magnets. He exclaims, in concluding his remarks on these results, "how rapidly the knowledge of molecular forces grows upon us, and how strikingly every investigation tends to develope more and more their importance, and their extreme attraction, as an object of study. A few years ago magnetism was to us an occult power affecting only a few bodies; now it is found to influence all bodies, and to possess the most intimate relations with electricity, heat, chemical action, light, crystallization, and, through it, with the forces concerned in Cohesion; and we may, in the present state of things, well feel urged to continue in our labors, encouraged by the hope of bringing it into a bond of union with gravity itself."

It is found, when the component atoms of a solid plate of copper, silver, &c., are disintegrated at the positive or delivering pole of a galvanic circuit, and are silently transported across the liquid medium in the vessel to the opposite receiving or negative plate, that the solidity or cohesion is perfectly restored; and that the newly deposited mass of metallic atoms exhibits the characteristic properties of hardness, of color, and of angular crystals, like a mass of the same atoms after being melted in a furnace, and cast in the usual way. But these properties admit of modification by varying the intensity of electricity employed in performing the process.

The quality of the deposited copper or other metal is found to be soft and flexible, when the current is maintained of such intensity that hydrogen is just on the point of appearing in bubbles on the surface of the mould. A black deposit takes place when the intensity of the electricity is too great in proportion to the strength of the solution. But if the strength of the solution be increased, and but little acid be added to it, the deposited metal is then found to be very hard, and composed of large crystals.

The copper deposited by this electrical process is also free from all foreign admixtures of other substances, which impairs its value essentially for use in the processes of engraving and etching. The plates, indeed, are absolutely pure; and Mr. Shaw states, that there can be no doubt that they will very soon completely supersede the ordinary plates of rolled copper employed for this purpose.

The crystals of the silver thus deposited are of a snowy whiteness. The crystallized grains of lead and bismuth are strikingly beautiful.

It is necessary to employ very feeble batteries to produce the most perfectly regular deposition of crystals of metals, as the rapid action of powerful currents of electricity mechanically disturbs the regular distribution of the elementary atoms, by nôt allowing time for them to become arranged in obedience to their relative polarized conditions.

FORMATION OF MINERAL CRYSTALS IN THE EARTH BY ELECTRIC AGENCY.

In the preceding accounts of the disintegration of the particles of solid metals and metallic salts, and of the transference of them through the liquids in which they are immersed, to form fresh deposits in new situations, we find analogies that lead us to apply these facts to the explanation of similar processes continually going on in the strata of the wet earth, wherein electric currents have been detected, circulating through the veins of minerals, or lodes of deep mines.

The various mineral strata arranged at different depths, and in layers of different thicknesses, which constitute the crust of the earth's surface, are composed of the several kinds of elementary atoms symmetrically grouped together in regular forms of crystals of quartz, lime, and other minerals. However these groupings of elementary atoms may be combined together, to form the apparently interminable variety of beautiful mineral crystals, yet it has been found that the searching power of a galvanic current will silently select the metallic particles therefrom, and will convey them to the opposite pole of the battery. It follows as an obvious deduction from the facts disclosed by the action of electric currents in the artificial process of Electro-metallurgy, that if there exist subterraneous electric currents in the lodes of the earth, as experiments with galvanic needles have indicated in the deep mines of Cornwall, there must be a constant electro-metallurgic process naturally going on in the strata of the wet earth.

To represent, artificially, the natural electro-dynamic action producing crystalline deposits in the veins of the earth, Mr. Crosse produced deposits of crystals of marble or limestone, between two pieces of bricks, by means of long-continued feeble electric currents. The cohesion of these deposits was sufficient to cement the bricks together, like the white veins which are commonly found cementing together masses of rocks.

It is stated by Mr. Fox, * that "he has succeeded, not only in forming well-defined metalliferous veins in a crack in the middle of masses of clay, by means of voltaic agency, but also in imparting to the clay a laminated, or schistose structure."

Among the veins thus produced between flakes of clay, Mr. Fox mentions "oxide and carbonate of copper, carbonate of zinc, oxides of iron and tin." At the lead mines in Wisconsin, I have seen the cavities of sea-shells, imbedded in calcareous rocks, perfectly filled with a deposition of the crystals of lead in the form of *galena*, in the same manner as a hollow mould.

It is familiarly known that the oxides of metals are usually found deposited in veins, or lodes, which are simply fissures between the separated parts of masses of rocks or earth, filled in with these foreign substances. If the fissures between two bricks, or the cracks in a lump of clay connected with the negative pole of a battery, may be thus artificially filled with deposits of various metallic, and other substances, consolidated from dissolved metallic, or other solutions, we may reason from analogy, that these deposits may represent very exactly the phenomena of the natural formations of veins of crystallized minerals, found beneath the surface of the earth, and in the seams constituting the streaks of quartz so commonly observable in white lines intersecting the rocks upon its present surface.

Even a feeble electro-dynamic action, steadily operating during protracted periods of thousands of years, may prove effective in accumulating immense aggregations of mineral masses, it having been found, experimentally, that the slower the action arising from feeble currents, the more cohesive and perfect are the crystals produced. Geologists are thus furnished with a new and demonstrably certain agency of electricity, to serve for explaining the mechanical formations of crystalline masses, constituting the materials subjected to their appropriate branch of scientific investigations.

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* Silliman's Journal, vol. 3, page 199.

It has been observed by Becquerel, * that by means of long-continued electrical action, Nature, having unlimited time at her disposal, produces, with slender means, immense results. By the long-continued action of very feeble galvanic, or thermo-electric currents, he succeeded in producing remarkable chemical decompositions, and in overcoming powerful affinities, which it was previously supposed could only be effected by currents of electricity possessing a considerable degree of energy.

This continuous propagation of terrestrial electric currents between atoms at insensible distances, when brought into contact with each other by the springs of water percolating the porous texture of the soils of various regions, and holding dissolved, or in solution, atoms of lime, and silicious rocks, metals, &c., is thus shown to be adequate to producing the groupings of atoms into the symmetrical arrangements of the beautiful angular crystals characteristic of all terrestrial matter.

The establishment of reciprocal mechanical action between atoms, constituting the phenomenon of Cohesion, is more remarkably illustrated by the effects of Organic than by those of Inorganic action. Among the labors of Agriculture, that of establishing Cohesion among the groupings of atoms of carbonic acid gas and water, holds an important rank. Every agriculturist, who sows the seeds of hemp, flax, and cotton, practically resorts to the mechanisms of the organs of these respective kinds of plants, for the express purpose of reducing the elementary molecules of gaseous carbonic acid gas and liquid water, from their natural static condition, to the constrained static condition of tenacious filaments. These vegetable fibres are adapted to form ropes, cables, and textile fabrics, capable of resisting powerful divellent impulses.

The agriculturist systematically exposes the germs of plants of hemp, flax, and cotton, to solar action on sunny plains and hill-sides, to court the desired electro-dynamic excitation relied upon for establishing an organic polarization of the atoms to produce Cohesion. This peculiar constrained electro-polarization of

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* Treatise on Chemical Decomposition and Crystallization produced by voltaic action.

water and carbonic acid gas constitutes the intrinsic value of these staple products of agriculture as articles of merchandise, interchanged between man and man in the commerce of the world.

The phenomenon of Cohesion admits of being established among the atoms of carbonic acid gas and water, and of being eradicated therefrom, at the pleasure of an experimenter. He may employ the *direct* propagation of the electro-dynamic action of the sun, concentrated by a convex lens or concave mirror, to induce a speedy polarization of the atoms, which is the reverse of that induced *indirectly* through the modifying intermediate agency of the mechanism of the organs of plants. He may thus counteract the Organic action of Cohesion, and resolve the atoms again into their natural Inorganic conditions of fluids, which are nearly devoid of every trace of Cohesion.

Then, by collecting these diffused fluids beneath a bell glass, and by again employing the organs of the germs of a plant of hemp, as an electrical machine excitable by the sun, he may re-establish the same Cohesion between the fluid atoms.

The continuous propagation of the electro-dynamic action of the sun in the modified forms of cohesion induced by Organic action, of mechanical action developed by the change of the grouping of atoms from one static condition to another in the modified form of Combustion,—and of the transference of these powers of dynamic action, successively, from grouping to grouping, admits of an instructive illustration by pursuing further this investigation. The fibres of hemp, wrought into a cable, constitute an emblem or type of Cohesion, as the familiar term, "strong as a cable," implies.

To prove, when the mechanical action and reaction constituting the Cohesive force of a hempen cable are resolved by the combustion of it, as has just been noticed, that there is propagated a resultant action, the vegetable fibres may be employed as fuel, to propel a sea steamer against the winds and waves; which they passively resisted whilst connected with the anchor.

After being partially burnt, or reduced to charcoal, the atoms of carbon still carry with them their organic force of cohesion; as is familiarly known in the employment of organic carbon inclosed in an air-tight box in contact with bars of iron. This constitutes the process of "Cementation," in the manufacture of steel cementing together the atoms of iron with double cohesive force. An additional extent of Cohesion, equal to that of the original hempen cable, may be thus transferred to the iron links of a chain cable; thus practically demonstrating, as it were, that "e'en in their ashes live their wonted fires!"

Steel, in turn, admits of propagating cohesive action in the modified form of magnetic attraction, as before stated; and thus the electro-dynamic action originating from the sun admits of being successively traced out through variously modified forms of cohesion, as well as of heat, light, electricity, chemical and mechanical action, &c.

The ELASTICITY of steel springs appears also to be thus traceable to the original electro-dynamic action propagated through the medium of electric matter, and excited by the action of the sun on the organs of plants. These group together the organic carbon which is combined with the iron in the preceding process of converting it into steel.

The Elasticity of organic formations, such as those of flexible wooden springs, of whalebone, &c., is as pertinaciously maintained as the elasticity of inorganic formations of metals. I have known the fact that a piece of hickory has endured more than two hundred vibrations per minute for upwards of twelve years. Watch springs, with their daily recoil, appear to retain their elasticity for indefinite periods.

That Cohesion is not an "inherent" property of steel, is manifest from the preceding statements; that it is really a mechanical effect produced by causes of electro-dynamic excitation, appears equally manifest. By figure 67 at page 310, the fact is shown that the steel file may be more readily cut in two by a revolving plate of thin sheet iron than the sheet iron ordinarily is by the cohesive power of the hardest tempered steel. The following details also show a remarkable instance of the establishment of a perfect state of Cohesion by the same mechanical cause of Compression, which has been found to be an unfailing cause of electric excitations.

By the violent compression of inelastic substances, as when cold iron is subjected to various manipulations in processes of the manufacture of this metal, intense electro-dynamic action in the form of heat becomes developed; and, what is a very surprising fact, a *perfect cohesion* of the particles of the iron appears to become re-established as firmly as by the common electro-dynamic process of welding accomplished by the thermo-electric excitations of a forge fire.

My attention was directed to the investigation of this phenomenon by the intelligent superintendent of a manufactory of iron screws, termed "wood screws."

In the process of wire-drawing iron rods, to reduce them to the desired sizes for screws, the texture of the metal becomes fibrous, and liable to become split longitudinally, whilst the intense compression of the heading-tool acts in flattening the ends to form the heads of the screws.

It appears from the examination of the ends of different pieces of the iron, withdrawn in an incomplete state from the machines after the ram of the heading-tool has been arrested in different stages of the process, that the fibrous wire becomes regularly split open by bulging out to the enlarged size of the screw-head. The split parts become closed again almost instantaneously during the rapid movement of the heading-tool.

Notwithstanding this separation of the parts of the iron heads of the screws, the intense compression employed is found to be adequate to reuniting the dissevered parts in such a perfectly solid *coherent* condition, as to show no flaws in the iron shavings turned off from the surface of the heads in subsequently reducing them to their finished shapes. By this test, a perfect state of cohesion of the metal is re-established by means of the intense electro-dynamic excitation produced by the compression.

That there is produced a very powerful thermo electric action by this violent mechanical compression, is manifest from the fact that the pieces of iron after being *headed*, and dropped in rapid succession from the machine, are so intensely excited by the process, that they cannot be touched without burning or blistering the fingers.

The establishment of Cohesion is here traceable to the mechanical action propagated by the steam power originating from the electro-dynamic action of the sun, which produces the fuel burnt beneath the boiler.

Before closing this subject of Cohesion, it may prove instructive to advert to the philosophy of the practical processes commonly employed for cutting and punching heavy plates and bars of iron in machine shops. The facility with which massive bars of iron are cut off with shears by the application of a moderate mechanical power, as compared with the divellent power necessary to pull them asunder, usually excites the wonder of every visitant of a machine shop.

From experimental observations I have been satisfied that this transverse mode of severing the atoms of a bar of iron is accomplished against a comparatively feeble resistance of the force of Cohesion. This force being in the direction of lines drawn between the centres of atoms at insensible distances, is analogous to the magnetic force exerted directly between the poles of two conjoined bar magnets. The ends of two magnets may be easily slided along laterally at right angles to the axes of the magnets. The same result is also accomplished with the smoothly polished adhering surfaces of two bodies, which may be slipped around with ease over each other's surfaces; whilst at the same time very powerful exertions may be requisite to pull them directly apart from each other. This same sliding lateral movement of the cohering atoms takes place in the process of cutting and punching iron. The major force of cohesion being in the line of the polar axis joining the centres of the atoms, and the shears or punches being directed at right angles to this force, they have the minor resistance of the equatorial reaction to encounter, as represented at A, figure 45, page 250, instead of encountering the major polar reaction.

These views of the polar and equatorial molecular actions and reactions confirm remarkably the preceding analogies of electrodynamic action as being identical with that of Cohesion.

Our limits will not admit of further pursuing these details, to illustrate that Cohesion is not an inherent property of matter; but simply a mechanical effect produced by an adequate cause of propagation of mechanical action originating from solar excitation.

These analogies admit of being almost infinitely extended to illustrate the fact of the continuous propagation of mechanical action through the medium of electric matter by regular stages of successive static and dynamic conditions of groupings of elementary atoms, such as are popularly recognized by the terms, HARDNESS, BRITTLENESS, FLEXIBILITY, &c., which constitute modified conditions of Cohesion.

IMPULSES OF MECHANICAL FORCE PROPAGATED DURING THE PROCESS OF CRYSTALLIZATION.

The establishment of the electro-polarization of atoms during the process of crystallization, and of the Cohesion which simultaneously ensues among the component atoms of symmetrical crystals, is experimentally found to be accomplished with irresistible energy. The strong and massive sides even of cannon and bomb-shells have been rent asunder by the mechanical force which moves and arranges the fluid atoms of water into their solidly-fixed conditions of crystals of ice. The bursting of a bottle filled with freezing water, is a representation on an enlarged scale of the rupture of the sap vessels of the leaf and blossom during a frosty night. The sere and withered leaf of autumn is the result of this violent mechanical action. In the phenomenon of the termination of the organic action of vegetable life in the autumn, as well as in the commencement of the budding germs in the spring of the year, we have annually presented before us interesting subjects for consideration, physical as well as moral.

In connection with the subject of the grouping of molecules of water into fixed cohesive arrangements of crystals of ice, we may take an exceedingly instructive view of the philosophy of the changes of the balance of power, vibrating in the modified form of Organic and Inorganic action. This annually is produced by the increasing ardor of solar excitation in the spring, and by its waning ardor in the autumn and winter of each year.

In treating of vegetable organic formations, the details have been given of the excitation of the mechanism of living plants by the increasing electro-dynamic action of the sun in the vernal season. Under peculiar circumstances this vegetabe Organic action becomes paramount to the same electro-dynamic action of the sun propagated in the modified form of the Inorganic action of terrestrial electric currents. The latter induce the electro-polarizations and consequent groupings of terrestrial atoms into crystalline masses, as previously described; the former induces the groupings of atoms of carbonic acid gas and water into organic formations.

When the direct propagation of the electro-dynamic action of the sun on a portion of the surface of the earth, and on the mechanism of the organs of living plants, declines below a certain limit of intensity, as indicated by the degree of the freezing point on the scale of a thermometer, then the indirect electro-dynamic action of the sun, propagated in the modified form of terrestrial electric currents, induces the polarization, and consequent crystallization or freezing of the atoms of water. Whilst subjected to the paramount sway of Inorganic action, the molecules of water in the sap vessels become arranged into crystals of ice, with the development of the divellent mechanical force above stated.

Whilst the electro-polarization of the molecules of frozen water sustaining the crystals of ice continues the same, the organic formation of the plant or animal remains unchanged, like the crystals of marble and brass, which are artificially chiselled to preserve the statuary outlines of their forms.

But when the more intense direct electro-dynamic action of the sun again overpowers its indirect action in sustaining the crystalline electro polarizations of the same molecules of water, then the atoms constituting the fixed groupings of vegetable and animal bodies yield to this more intense inorganic electro-polarization. Then a new order of reciprocal attractions and repulsions become developed between the constituent atoms at insensible distances.

Under the influence of this new order of polarization, the Organic action yields to this paramount Inorganic action. The beautiful organic forms of flowers, and the lovely forms of once animated beings, become now speedily changed into their natural static conditions of gas and water, in obedience to the all-controlling sceptre of an universal electro-polarizing power, when, as poetically described,

——— "decay's effacing fingers,
Destroy the lines where beauty lingers."

The leaves of the evergreens, which survive the frosts of winter, owe their escape from this general doom to the absence of watery juices, the crystallization of which proves destructive to the organizations of deciduous plants. The sap of the leaves of evergreens consists of essential oils, as is tested by the fact of the extraordinary combustibility of the green leaves of the spruce, pine, and other similar plants.

I have seen even the massive trunks of trees rent open, with gaping seams, by the crystallization of the sap within them. Thus are produced the seams in timber-trees, which essentially impair their value in the estimation of the carpenter.

The powerful action developed by the crystallization of water is familiarly discoverable in the crumbling of plastered walls. The philosophy of the preservation of such walls from dilapidation consists in the exclusion of water from their porous texture. The preservative effect of a coating of paint is ascribable to the exclusion of water, thereby accomplished.

As a wash of hydraulic lime or cement possesses in an eminent degree the power of excluding water from porous bodies, it serves to protect plastered walls exposed to the weather. But as this artificially prepared substance becomes also speedily crystallized or *set*, like plaster of Paris, on being mixed with water, it should be used within a few minutes after it is slaked.

It is a common practice to rely upon the crystallization of sulphur, after being melted and poured around iron bolts and bars, inserted in holes drilled in stones, for the purpose of fixing such pieces of metal solidly therein. When this plan is resorted to, without carefully considering the strength of the parts of the mass of the stone to withstand the electro-dynamic force brought into action during the process of crystallization, they are burst asunder and shattered. The destructive effects produced by an ignorance or neglect of this important physical law, I have often had occasion to witness in th emutilation of hewn stones of copings of walls, of stone steps, pillars, &c.

The introduction of particles of water into the pores of granite rocks, and the subsequent crystallization of them there during frosts, serve to rupture the pores, and to disintegrate the surface of the rock. The dew-drops, silently gathered upon the marble monument erected by man to perpetuate the record of his name, after sparkling for a moment on its polished surface, penetrate the porous texture of the stone, the crystallization thus overpowering the cohesion, and reducing to illegible dust the tablets on which are engraved the inscriptions designed to perpetuate human friendships and human greatness.

The same electro-dynamic agency, which teaches this humiliating lesson to human pride, serves usefully to crumble the surfaces of mountains of barren rocks into fruitful soils adapted to the luxuriant support of vegetable life.

This brief review of the mechanical action developed during the change of electro-polarization of atoms in the process of crystallization will here be terminated at the threshold of another branch of mechanical science, which is specially appropriated to the consideration of the action of forces at insensible distances between different kinds of elementary atoms. This peculiar kind of molecular action is termed Chemical Affinity.

THE CONTINUOUS PROPAGATION OF THE ELECTRO-DYNAMIC ACTION OF THE SUN CONSIDERED AS THE ORIGINATING CAUSE OF THE PHENOMENA POPULARLY ASCRIBED TO

CHEMICAL AFFINITY.

"Throughout the whole kingdom of Nature, whatever change may occur in a body, whether it be relating to rest or to motion, or to a change in its aggregate condition, must be occasioned by some force."—*Muller.*

In tracing out to an originating source the effects of the development of impulses of mechanical force between different kinds of atoms at insensible distances from each other, constituting the phenomena ascribed to Chemical Affinity, it will be profitable to take a brief preliminary view of the doctrines applicable to this inquiry, which are taught in the popular treatises on Chemistry now used as text-books in colleges and schools. Our prescribed limits will confine this essentially important investigation to a few pages, condensed from numerous sheets of manuscript.

Popular Doctrines of the Natural Motive Power, producing the mechanical action between different kinds of atoms at insensible distances, constituting the phenomenon of CHEMICAL AFFINITY.

In Dr. Turner's very popular treatise on Chemistry,* it is stated, that Chemical Attraction, or Affinity, "is distinguished from Cohesion by being excited between dissimilar particles only, while the attraction of Cohesion unites similar particles."

"All chemical phenomena are owing to Affinity, or Chemical Attraction. It is the basis on which the science of Chemistry is founded.†"

"The phenomena of Crystallization, are owing to the ascendency of Cohesion over Affinity," and "Cohesion sometimes determines the result of Chemical Action, probably even in opposition to Affinity. Elasticity operates likewise as a decomposing Agent," &c. The intelligent editor of the 6th American edition of Turner's Chemistry, Professor Bache, explains in a note, that "the force which tends to bring the elementary molecules into closer proximity, is derived from an *innate* property of ponderable matter, while the force which tends to separate them is dependent on the operation of a distinct principle, *Caloric*, the particles of which being self-repellent, force the ponderable particles asunder."

In the recently revised edition of Chemistry, published by Professor Graham, president of the Chemical Society, London, page 217, the following outlines are given of Chemical Affinity:

"Chemistry is more than a descriptive science; for it embraces, in addition to views of composition, the consideration of the action of bodies upon each other, which leads to the formation and destruction of compounds."

"A specific attraction between the different kinds of matter must be admitted as the cause of combination, and this attraction may be conveniently distinguished as *Chemical Affinity.*"

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* 8th London edition, by Gregory and Liebig, page 4.

† Page 130.

"The actual phenomena of combination suggest the idea of peculiar attachments and aversions subsisting between different bodies; and it was in this figurative sense that the term *affinity* was first applied by Boerhaave to a property of matter."

From a supposed resemblance of these reunions to those formed by the matrimonial alliances of human beings, the term "elective" has been superadded to "affinity," to denote more especially the farther apparent resemblance of the preferences and dislikes of lifeless atoms, to those of intelligent living beings. But there is evidently more of poetry than of science in this ascription to lifeless atoms of self-motive, and self-directive powers, together with a degree of perceptive intelligence, which enables them, when brought together in solutions, without mistake to recognize each other, even in the dark, where human lovers might be at fault.

To admit of the existence of self-originating motive power in each atom, is to concede to lifeless matter more than is conceded to living organic matter; for all animal motive power is known to originate from, and to be measured in intensity by, the combustion of food in the lungs.

Dr. Hare considers * that the phenomena of chemistry demonstrate that there are at least the three following properties in matter:—

"1st. An innate property of reciprocal attraction.

"2d. An innate property of counteracting attraction directly, by imparting reciprocal repulsion.

"3d. An innate property of imparting attraction, variable in its force, and limited and contingent in its directions."

Innumerable similar opinions of the "inherent" and "innate" properties of matter pervade all the chemical text-books; as also they prevail in philosophical works in reference to the phenomenon of Cohesion, as has been stated in treating of that subject.

With all this unanimity in adopting doctrines of "Inherent powers," strange as it may appear, chemists have readily admitted the doctrine of mechanical science, teaching the passiveness of matter. It is affirmed by Dr. Turner, in the first page of his Introduction, that, "matter, though susceptible of *rest* and *motion*, has no inherent power either of beginning to move when at rest, or of arresting its progress when in motion. Its indifference to either state has been expressed by the term *vis inertiæ*, as if it depended on some peculiar force resident in matter; whereas it arises from matter being absolutely passive, and thereby subject to the influence of every force capable of acting upon it."

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* Page 3, of 4th edition of Hare's Chemistry.

If we suffer ourselves to depart in one single case from the principles of mechanical science, establishing that matter cannot move itself when at rest, by admitting that atoms at insensible distances can reciprocally unite themselves, and disunite themselves, by chemical compositions and decompositions, and that they can self-originate violent impulses of mechanical force, such as occur in innumerable cases of chemical explosions, we abandon all the advantages which have been obtained by the experience and observations of mankind acquired in past ages, and handed down for our guidance. That man would be deemed a rash navigator, who would now reject the advantages of the charts, the compass, and the sextant, which the experience of former navigators has prepared for his use; and trust his course to the guidance of his imagination.

It follows, as a consequence of the admission of the chemical theory of the existence of "Inherent Forces," in the different kinds of elementary atoms, that all ideas of the causes of impulses of mechanical force *extrinsic* to such atoms are utterly precluded. Indeed, this doctrine extorts the belief, as before stated, that the atoms of lifeless matter possess more extraordinary acuteness of discernment than human beings endowed with intelligence and elaborate organs of perception; for the most skilful chemist has recourse to various kinds of atoms as tests of the presence of certain others in compound solutions; and the skilled mason and engineer deferentially submit to the superior guidance of the plumb-line, and spirit-level, to find vertical and horizontal lines. In the same manner, the pilot follows the guidance of his magnetic needle, without which, as in the voyage of St. Paul, "men were at their wit's end."

It is our aim to show that the same law which governs the movements of the polarized needle, controls also the polarized conditions of all the atoms of terrestrial matter, whether at sensible or insensible distances.

In explaining the difference between the *electrical* and *chemical* theories of the voltaic circuit, Professor Graham affirms that "polarity of molecules is supposed in both views, but in one view the polar forces are the *two* electricities, in the other, *two* chemical affinities." He continues, "The electricities are supposed to be the cause of the chemical affinities; but it may with equal justice be assumed that chemical affinities are the cause of the phenomena reputed electrical."

The question then is, Professor Graham asserts, with the chivalrous zeal of a true scholar devoted to a favorite science, "Whether these forces are electrical or chemical? Shall Electricity supersede Chemical Affinity, or Chemical Affinity supersede Electricity?"*

In this question, the issue is fairly joined. On the result is finally involved the subversion or establishment of conflicting fundamental principles of the sciences of Chemistry and of Mechanics. The difference between the present popular chemical doctrine of "Inherent" forces, and the mechanical doctrine of the "Inertness," or incapability of matter to move itself, is absolutely irreconcilable; and the one doctrine or the other must finally prevail.

In maintaining the supremacy of chemical science, the learned Professor asserts, that "All electrical phenomena whatever are found to involve the presence of matter, or there is no evidence of the independent existence of electricity apart from matter; so that these phenomena *may really be exhibitions of the inherent properties of matter.*"

In explaining electrical forces, Professor Graham admits as "one reason for retaining the theory of an electrical fluid or fluids, that it affords the means of expressing in distinct terms these strictly physical laws, which are *reputed electrical;* but it has nothing to recommend it in the description of the chemical phenomena of the voltaic circle. These admit of a perfectly intelligible statement, when viewed as exhibitions of ordinary Chemical Affinity, acting in particular circumstances, *without any*

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* Graham's Chemistry, page 162, Am. Reprint.

electrical hypothesis. It it often said that chemical affinity acts only at *insensible* distances, and this may be true of its direct action; but it is not inconsistent with its exerting an influence at a distance, like many other forces," &c.

But after viewing the palpable impulses of mechanical force exerted on bodies, as manifested by their reciprocal movements not only toward and from each other, as exhibited in the phenomena of attraction and repulsion, but also by their continuous reciprocal revolving movements about each other, as exhibited in the apparatus of the revolving magnets and conducting wires, which are found in every lecture-room, the Professor exclaims, to use his own words, "*something* does pass through the wire in these circumstances, as is proved by its becoming heated, and by its temporary assumption of certain electrical and magnetical properties."

Thus confusedly blended are popular ideas of the causes of chemical action, of electrical action and of natural motive power, as taught by some of the most recent writers on the science of chemistry. No reference is made by them to the originating cause of the mechanical impulses developed, or to the laws of motion and force that govern the states of motion and rest of all terrestrial matter.

There appears to be a very good reason why chemists should avoid these investigations of the causes of natural motive power, which produce the effects of the unions and separations of the atoms of compound substances, as well as the consideration of the laws of motion and force, which it is the peculiar province of the science of mechanics to investigate. By simply confining the range of chemical investigations to the descriptions of established facts of the groupings of atoms of the different kinds of elementary substances into compound bodies, and of their decomposition, with that of the simultaneous development of the phenomena embraced under the comprehensive term of "Chemical Action," a degree of positive certainty is imparted to the study of chemistry, which throws over this branch of science a charm of perfect truthfuluess, that constitutes the most fascinating attraction of the exact science of mathematics.

It is therefore allowable for chemists to dispense with the consideration of the nature of the mechanical forces which are developed between the atoms of the different kinds of elementary substances at insensible distances from one another, as it is allowed to astronomers to dispense with the consideration of the nature and causes of the impulses of mechanical force which are developed between the huge orbs of matter in the depths of the heavens. Both chemistry and astronomy are sciences strictly descriptive of mechanical results produced; and although the causes of these mechanical results may remain for ever undiscovered, yet the truths taught by these sciences cannot be invalidated thereby.

These reflections lead to the conclusion, that by attempting to elevate chemical science above its true rank as a branch of mechanical science, and by assigning an equivocal origin of the cause of chemical forces, in the adoption of the popular terms "*innate*" and "*inherent forces of matter*," chemical doctrines become unnecessarily embroiled in doubts and distrusts, which degrade them from the lofty elevation of a perfectly truthful science.

As an offset to the current of opinions popularly maintained in opposition to the idea of the excitation of chemical action by electrical agency, several distinguished chemists have maintained that Chemical Affinity is due to electrical action. The discussion of this subject has been anticipated at page 312, in treating of Chemical and Contact theories of electricity, where it has been shown that the excitation of galvanic electricity does not originate from the chemical decomposition of water, but on the contrary, is caused by the recoil of the atoms of zinc from their artificially-produced static conditions of a pure metal, to their natural static condition of an ore, or oxide.

Sir Humphrey Davy maintained, that there exists among all substances which become combined together chemically, opposite electric states, which become manifest by their reciprocal contact; during which process the phenomenon of *fire* becomes manifest, that is, *light* and *heat*, in consequence of the re-union of the two electricities. Then the chemical combination is established.

Berzelius has thrown the weight of his sagacious remarks into the same scale, and established the basis of modern electro-chemical science, by showing the relationship between the electric powers of bodies, and their chemical properties, in his preliminary examinations of the two primary questions of the existence of electricity in connection with elementary atoms, and of their relative electro-positive, and electro-negative conditions, in various degrees of intensity.

It remains now to be shown, on the other hand, that the propagation of the electro-dynamic action of the sun between atoms of matter at insensible distances, through the medium of the perfectly mobile electric matter, is capable of inducing all the decompositions and recompositions of groupings of elementary atoms, which constitute the phenomena of "Chemical Action;" that, in fact, Chemical action is identical with, instead of being a cause of, Electro-dynamic action. The cause of Chemical Affinity being defined to be "a specific attraction between different kinds of matter," and specifie attraction being considered as limited to "atoms at insensible distances from each other," this investigation carries us back to the previous discussions of the occupancy of space by atoms. It has been recapitulated at page 22, that all knowledge of the modified forms and properties of matter is derived from the mechanical action which groups individual atoms into masses of discoverable magnitudes. And in treating of the different kinds of elementary substances, they have been considered (page 72), as constituted of sixty specific Inorganic groupings of atoms, endued with sixty different grades of powers of modifying the propagation of the electro-dynamic action of the sun: as about half a dozen kinds of atoms are endowed with nearly half a million of different grades of powers of grouping organic formations of vegetable and animal bodies, each endowed with specific powers of modifying the propagation of the same electro-dynamic action. This assumption is in strict accordance with a well-ascertained system established in the Mechanics of Nature.

This supposition is corroborated by the facts recapitulated at page 90, showing that the chemical character of a compound does not so much depend on the *nature* of its component elements, as on their grouping and arrangement. For this reason it has been assumed that the cause, which produces the chemical character of compounds, must be identical with the cause which produces the mechanical arrangement of the grouping of atoms.

From the preceding synthetical principles may be deduced the following *Mechanical System of Chemical Affinities:*

The electro-dynamic action of the sun on the orb of terrestrial matter is continuously propagated in *three* distinctly modified forms.

1st. By a general solar radiation upon the entire hemisphere of the orb of the earth, inducing the propagation of terrestrial electric currents from east to west, about its circumference (figure 27, page 229), and a general polarization of the whole orb, with a specific polarization of every atom of the orb (fig. 46, page 252).

This general cause of the electro-polarization of the mass of the earth, and of the individual atoms of the mass, induces the phenomena of crystallization, and the natural states of rest of terrestrial matter, which have been denominated (page 25) the *Natural Static Conditions of Inorganic formations.*

The same groupings of atoms are treated of in Inorganic Chemistry, under the name of *Inorganic Chemical Combinations.*

2d. By a partial solar radiation upon specific portions of lifeless matter, whereby the natural static condition of the groupings of such specific portions of matter (corresponding with Inorganic Chemical Combinations) is disturbed, as in the modified forms of the excitation of Heat, Light, Electricity, Chemical Action, &c. This has been detailed (page 44) with reference to the continuous propagation of electro-dynamic action, originating from solar excitation, and at page 468, figure 117.

3d. By a partial solar radiation upon specific portions of the matter of the organs of living plants, as has been described (page 96) in treating of vegetable Organic Formations. This modified form of the propagation of electro-dynamic impulses constitutes Organic Action (page 272).

The static and dynamic conditions of groupings of atoms produced in this peculiarly modified form are treated of as *Food and Fuel* (page 107). They are treated of in chemical works, under the subdivision of Organic Chemistry.

By means of these variously propagated electro-dynamic impulses, originating from the sun, all the phenomena of the states of motion and rest of terrestrial matter may be systematically traced out.

The *general* solar action on the hemisphere of terrestrial matter tends to bring all individual atoms to their natural static condition of fluid and solid Inorganic formations.

The *partial* solar action on portions of lifeless Inorganic matter, serves to induce local disturbances of the natural static condition, which would otherwise universally prevail, and hold all matter in relative fixed states of rest and crystalline arrangements.

By the changes of the seasons, the partial solar action alternately overpowers the general solar action, and is overpowered thereby. The alternations of the crystallization or freezing, and of the thawing of water in winter and summer, exhibit a type of these modes of propagation of electro-dynamic action.

The same fluctuations of electro-polarization of terrestrial atoms constitute the phenomena of Attraction and Repulsion, recognized as Inorganic Chemical Action and Reaction.

The partial solar action modified by the organs of plants and constituting Organic action, has been shown (page 107) to be propagated in reducing carbonic acid gas and water from their natural static conditions, to constrained static conditions of groupings of fuel and food. Both the general and partial solar action on lifeless terrestrial matter, constituting Inorganc action, it has likewise been shown, react antagonistically to Organic action; and, when paramount in intensity, produce the recoil of all organic formations from their constrained static conditions of groupings to their natural static conditions of carbonic acid gas and water. The process of this Inorganic reaction is denoted (page 141) by the terms, *Chemical Decomposition*, *Fermentation*, and *Combustion*. It is accompanied by the development of mechanical action in the modified form of *heat*, *light*, and *electricity*, which constitute the chemical "IMPONDERABLE AGENTS."

The investigation of the phenomena exhibited during the recoil of the Inorganic action against the Organic action, successively from one static condition of groupings of atoms to another, with the propagation of electro-dynamic action during each successive change of groupings of atoms, constitutes the science of Organic Chemistry.

The successive changes of the groupings of atoms induced by the alternate prevalence of the above specified general and partial electro-polarizations of atoms, uninfluenced by the mechanisms of the organs of plants, constitute the phenomena of Inorganic Chemistry.

This classification of the formations and forces developed by terrestrial matter, is common to both Chemical and Mechanical sciences.

To carry out farther these analogies here, would be a divergency from the illustration of general principles of mechanical science in order to pursue the details of the subordinate branch of the science of chemistry.

The groupings of atoms of lifeless matter into inorganic formations, are found to propagate electro-dynamic action between their respective centres in three specific directions, viz., *toward*, *from*, and *about* each other's centres, as recapitulated at page 170. Organic action electro-polarizes and arranges atoms in various artificial directions, like galvanic batteries, in accordance with the determinate arrangements of the parts of vegetable and animal mechanisms.

The functions of the groupings of atoms both into inorganic and organic formations have been traced throughout all the preceding synthetical investigations to the endowment of them severally with specific powers of modifying the propagation of mechanical impulses originating from the electro-dynamic action of the sun—not to the endowment of "inherent" and "self-originating" powers. All elementary matter has been considered to be passive; and simply to be capable of propagating the electro-dynamic action imparted to it, like the prism, which only modifies the directions and intensities of the solar action upon the electroscopic nerves of the eye.

A few of the facts showing the identity of mechanical, of electrical, and of chemical actions, which have led to the preceding conclusions, will be here referred to in closing this article.

The identity of mechanical and electrical impulses has been proved at page 42, where it has been stated that an impulse of mechanical force, when once propagated from the sun to terrestrial matter, must continue to be propagated for ever by a successive series of actions and counterbalanced reactions, through the medium of perfectly mobile electric matter; and that an impulse of mechanical force becomes thus as indestructible, as the portions of matter which serve passively to receive and transmit it. The original electro-dynamic action of the sun, propagated through the medium of electric matter, exciting the organs of plants for the purpose of reducing water and carbonic acid to the consolidated state of fuel, has been traced out (page 44) in the successively modified forms of *steam power*, *electric excitation*, *heat*, *light*, *cohesion*, *magnetic action*, *chemical action*, and *animal motive power*.

A difference of distance, whether at insensible or sensible distances, cannot change the nature of a mechanical impulse, as noticed at page 312. *Chemical* action is therefore only a modification of *mechanical* action. In the chapter on the excitation of galvanic electricity, at page 316, it has been shown that the excitation of a galvanic battery does not originate from the chemical decomposition of water, but on the contrary, produces this chemical decomposition; as has been illustrated by figure 100, page 400. This chemical decomposition is an effect of polarization, produced by the propagation of mechanical action through the medium of electric matter; and the chemical recomposition of water has also been shown to occur in the use of the voltameter, (figure 51, page 260,) by the electro-polarization induced by an electric spark. Indeed an universal system of electro-polarization has been traced out by the preceding synthetical chain of facts.

Whether we employ frictional electricity, excitable by the motive power of the human hand applied to turning the crank of an electrical machine, for charging Leyden Jars, or the Zinc of the galvanic battery, for the purpose of chemically decomposing water, the propagation of electro-dynamic action is traceable from the originating cause of solar excitation, exerted on the organs of plants in the one case to produce the *food*, and in the other the *fuel*, which on their recoil in the lungs, and in the smelting furnace, serve to produce the results of the "chemical decomposition" of the water in the voltameter.

The space occupied by the commingled gases in the top of the tube of the voltameter, figure 51, page 250, after they are explosively reunited by an electric spark, becomes immediately filled with the water from the vessel below it. Every thing is then restored to precisely the same state as at the outset of this experiment; and this same process of "Chemical Decomposition" and of "Chemical Recomposition" admits of being indefinitely repeated by *electrical* agency.

By referring to the account of the decomposition of water by the apparatus of the voltameter, it will be remembered that the atoms of oxygen of the water always go to the point of the wire which delivers the electro-dynamic impulses, constituting the positive pole, whilst the atoms of hydrogen go to the opposite or receiving point or pole; and the same result is represented by figure 100, page 400.

This same principle admits of being practically extended to the separation of the atoms of every known compound substance, when reduced to a freely movable condition in their states of solution. Even solid substances are transferable, atom by atom, from one battery pole to the other, whilst immersed in fluids. Compound substances having an alkaline base, such, for instance, as table salt, Epsom salts, Glauber salts, potash, &c., all become "chemically decomposed" by the electro-dynamic action of galvanic batteries, the *alkalies* being determined to the one point or pole of the connecting wire, and the *acids* to the opposite pole. Thus the grand distinction between *acids* and *alkalies*, which constitute the principal "agents" and "reagents" for producing nearly all the chemical actions and reactions in the manipulations of the labratory, is demonstrable to be founded on the basis of electro-dynamic action.

One of the principal tests relied upon by chemists for determining the acid and alkaline action of various compound solutions is the *change of color* from *blue to red* or *from red to blue*, of various vegetable substances, such as an infusion of blue cabbage water, or of various mosses or lichens boiled in water. Paper steeped in these infusions is dipped in the acids or alkalies to be tested. If a bright red color be the result, the solution is pronounced to be *acid;* and if, on the other hand, a deep blue color appear, then the solution is deemed to be *alkaline.*

By inserting the two opposite poles of a galvanic circuit in the same vegetable infusions, precisely the same changes of color are produced, as when acids and alkalies are introduced as chemical agents.

As the two points or poles of the conducting wire, used in these experiments, are separated from each other, it follows, as a matter of course, that the different compound atoms on severally going to these remote points, must also *become separated from each* *other.* This separation is thus really a mechanical effect produced by the modified propagation of the electro-dynamic impulses, although it constitutes an essential phenomenon of "chemical decomposition."

That the source of the motive power in this case of chemical decompositions is not "*inherent*" in the atoms, is demonstrable from the fact that their movements take place in accordance with the artificial modifications of the directions of the impulses propagated through the conducting wire. By reversing the connections of the wires with the battery, precisely opposite movements of the chemical atoms are producible.

Nor are these chemical decompositions and recompositions produced with an equivocal feeble energy of action. On the contrary, substances which were always supposed to be simple, have recently been discovered to be composed of groupings of two or more different kinds of atoms, by the separation of them by means of the overpowering impulses of mechanical force, propagated through the medium of electric matter. The glorious discovery was thus made by Sir Humphrey Davy, showing that potash and limestone are composed of atoms of glittering metals of a silvery lustre, chemically combined with atoms of oxygen and carbon.

Davy originally placed a solution of potash in a cup between the two points of the connecting wire of a galvanic battery, when he perceived the atoms of a *new glittering metal*, never before seen by human eyes, which he named *potassium.* The clustered atoms of the metal gathered about the receiving or negative point of the wire, and the atoms of oxygen, previously united with them inseparably, appeared about the opposite positive point. An absolute "chemical decomposition" was thus effected by electrical agency, which had never been accomplished previously by any of the most efficient chemical agents employed in the laboratory.

By means of electrical action Davy also demonstrated that the limestone rocks constituting mountains, and the snowy marble in the hands of the sculptor, are composed of a metal of resplendent silvery lustre, united with carbonic acid gas. This metal he named Calcium.

By the use of the two points or poles of the connecting wires of a galvanic battery, it has been found that the atoms of nearly every kind of compound substance may be separated from their "chemical combinations," and become "chemically decomposed" by electrical agency.

By pursuing these experiments upon various compound substances, composed of groupings of the several different kinds of elementary atoms, the discovery has been made that there is a systematic gradation, or scale, of their determinations to the one or the other pole of the battery wire. One kind of elementary atom is always found to be urged to the positive pole, when decomposed from its grouping with certain other kinds of elementary atoms; which latter are found to be simultaneously urged to the opposite negative pole. This fact demonstrates that in their natural relative condition of groupings into compound substances, the different kinds of atoms are endued with powers of *modifying* the direction of electro-mechanical impulses, although, as has been shown, not of *self-originating*, the propagation of such impulses.

By extending this comparative test throughout the series of the simple elementary atoms, Berzelius ascertained that the atoms of oxygen take the precedence of all other kinds of simple substances in always going to the delivering or positive pole, and the atoms of the metal potassium, always take the precedence in going to the receiving or negative pole. Thus he formed his Table of the relative electrical powers of the different kinds of elementary atoms, as detailed at page 78.

These few brief outlines will suffice to impart an idea of the paramount agency of impulses of mechanical force propagated through the medium of electric matter in producing the phenomena of "chemical decompositions" and of "chemical action."

So well established indeed has become this practical mode of producing chemical decompositions of the groupings of atoms of various compound substances, that Professor Faraday has invented a new term expressly to denote this process, viz: ELECTROLYSIS, derived from two Greek words signifying *set free* by *electricity*. The atoms thus set free are termed "Electrolites."

That the primary chemical decomposition of the zinc in the battery cell is an effect produced by its recoil, as before stated, and by its consequent propagation of electro-dynamic action, instead of its being passively decomposed by "chemical action," is strikingly illustrated in the operation of batteries composed of zinc coated with mercury. The amalgamated zinc plate remains immersed in the acid of the battery cell, without exhibiting any chemical action, until the instant of the contact of the ends of the wire forming the circuit between the opposite poles; after which the electrical action and chemical action become simultaneously, if not identically, developed. If chemical action were the innate and inherent original cause of the electro-dynamic impulses in the preceding case, there is no reason assignable why chemical action should cease when the electric circuit is interrupted. But when we notice that the chemical phenomena in the battery trough cease and reappear in accordance with the interruption and re-establishment of the electric circuit, it is difficult to imagine that the latter is not the originating cause of the former.

The most extraordinary effects of electro-mechanical separations and groupings of atoms by electrical agency are those producible in the process of decomposing atoms of solid bars of silver, copper, and other metals, including even stones, and of transferring them across liquids to become re-grouped in their former crystalline arrangements, and with the revival of all their former characteristic properties of "cohesion," as previously referred to in treating of crystallization.

"In defining "Chemical Affinity" in chemical treatises, it has been usual to distinguish it from "Cohesion," which is exerted also between atoms at insensible distances, by limiting the application of the former term to the reciprocal action and reaction between *different kinds* of elementary atoms. Dr. Turner observes (page 489, Gregory and Liebig's edition), "We are repelled by the idea of *atoms of the same kind* having the relation to each other of combination; for diversity of nature appears to be the reason why bodies combine. The intensity of the combination certainly increases with the diversity; but this does not prove that such diversity is an essential condition of combination."

If "*diversity of nature*" be the reason why bodies combine, and "such diversity" be not "an essential condition of combination," in the words above stated, we frankly acknowledge our inability to comprehend how Chemical Affinity can be either an essential, an inherent, or an innate property of ponderable matter.

Although any one kind of elementary substance, taken singly, or absolutely by itself, may manifest no tendency to go to either pole of the galvanic battery, yet when any two of them are brought into contact with each other, and then separated, it follows as a consequence of the principle of the inductive excitation established by the contact and approximation of bodies, that the electric matter existing in connection with both bodies will become disturbed, and will develope oppositely directed impulses, or negative and positive states, as tested by their respectively becoming urged to the two opposite poles of the galvanic battery. The same kind of elementary atoms, which are found to become urged toward the positive pole after being subjected to contact with one particular class of elementary atoms, may be subsequently found to become urged to the opposite battery pole after having been subjected to contact with some other class of elementary atoms. The mere contact of one metal with another immersed in acids, protects one of them.

These developments of electro-dynamic impulses between different kinds of elementary atoms are not therefore ascribable to an absolute inherent power innate in such atoms, from the extremely negative oxygen and extremely positive potassium, which stand at the head and foot of the list of elementary substances; but they are rather ascribable to contingent powers of modifying the propagation of electro-dynamic impulses originating from an external cause, which we have ascribed to the continuous propagation of the electro-dynamic action of the sun.

The powers which modify the propagation of solar action developed by lifeless inorganic groupings of atoms, are less remarkable than the powers of living organic groupings of vegetable and animal mechanisms. In mechanical and in chemical sciences, the Organic action exhibits far more diversified and surprising effects of static and dynamic conditions of groupings of atoms, constituting chemical combustions, than the Inorganic action to which we have just adverted.

The electro-dynamic action of the sun on the organs of plants is not only adequate to collecting and grouping into the symmetrical forms of their bodies the elements of water and carbonic acid gas, and to developing their perfect mechanisms as real chemical laboratories, but also to imparting to these very same kinds of elementary atoms new and directly opposite chemical properties of *Acids* and *Alkalies*.

The juices of innumerable fruits, such as the lemon, quince, apple, grape, &c., are familiar instances of the imparting to groupings of atoms of carbonic acid gas and water the chemical properties of *acids;* whilst the juices of the poppy and of the bark of numerous plants, popularly known as *morphine*, *quinine*, *strychnine*, *emetia*, &c., exhibit the chemical properties of *alkalies*.

In a recent edition of a popular work on chemistry, there are enumerated one hundred and sixty-two different kinds of *organic* vegetable and animal acids, each one endued with such remarkably distinct grades of characteristic properties, as to render it worthy of a separate description.

The vegetable acids exhibit in their composition a grouping of a larger portion of atoms of oxygen, without the presence of atoms of nitrogen; whilst the vegetable alkalies appear to contain minute portions of nitrogen.

The association of 1 atom of nitrogen in a grouping with 10 atoms of carbon and 8 of hydrogen, is produced by the action of solar excitation on the organs of the tobacco plant. The organic forces thus established in a temporary constrained static condition in connection with this grouping of organic formations produce a compound having an alkaline action, and also a very exciting influence on the sensitive nerves of animals. Chemists have given the name of NICOTINE to this vegetable organic formation which propagates an action on the nerves of smelling and taste. The extent to which the use of the tobacco plant has been carried on account of this powerful development of an originating electro-dynamic action from the sun and propagated to the nervous systems of human beings, may be deemed one of the most wonderful facts in the physical history of mankind.

The concentrated extract of nicotine, when brought into contact with the nerves of the stomach, developes such powerful vegetable organic action as to counteract the organic animal functions. It operates as a frightful poison. "One fourth part of a drop is sufficient to kill a rabbit, and one drop a dog." When the leaf of the plant is chewed by the highest class of bipeds, it produces narcotic effects, and serves to render them ewhat stupefied and unattractive.

Still another relative proportion of organic groupings of atoms of carbon and hydrogen with an atom of nitrogen, constitutes the vegetable organic formation known as *quinine.*

Several of the organic vegetable formations which develope the chemical properties of acids, are recognized as articles of commerce, constituting the vegetable *oils.* Hence chemists have termed olive oil, "oleic acid," and palm oil, "palmetic acid," &c.; and the solid portions of the fat of animals, as of oxen, sheep, hogs, and also of human beings, they have termed *marganic* and *stearic acids;* whilst the oily part of butter, they have designated as *butyric* acid.

As the Organic and Inorganic groupings of atoms into acids, and into alkalies, have a tendency to become chemically combined together, and to counterbalance each other's powers of action, by becoming reduced to a static condition (chemically termed neutralization), the process of soap-making becomes thus resolvable into the neutralization of the characteristic organic action of vegetable acids, and of the inorganic action of mineral alkalies.

It may be noticed here, that the alkaline lye obtained from the lixiviation of wood ashes, is the dissolved oxide of a bright silvery-colored metal collected from decomposing quartz and other stones in the earth about the roots of plants.

This subject will be pursued a little farther for the purpose of employing the facts developed by chemical science, to establish the hypothesis that the characteristic properties of the sixty different kinds of simple elementary substances are due to powers of propagating the electro-dynamic action of the sun consequent on the groupings of their atoms, instead of being due to "inherent" or "innate" powers.

The grouping of atoms of oxygen and hydrogen into common water, are of so fixed a character, and exhibit such peculiarly characteristic properties, as to have led mankind to believe water to be a simple elementary substance until recently, in the history of science. The fixed characteristic properties pertinaciously retained by various groupings of atoms into the static conditions of both organic and inorganic formations, represent powerful *acids* and *alkalies.* Some of these acids and alkalies play the part of simple substances in resisting artificial attempts to decompose them. They pass through the ordeal of various chemical combinations and decompositions unchanged.

This is exemplified in the grouping of one atom of nitrogen with four of hydrogen, constituting ammonium. This compound acts like a simple substance, or base of one of the simple metals, in developing the characteristic alkaline properties of soda or potassa. This grouping of atoms constitutes the distinct classes of salts, known as the *salts* of *ammonia.*

Another instance is afforded in the grouping of one atom of hydrogen with one atom of chlorine, constituting a class of powerful acids, denominated *hgdracides*, or *hydrogen acids.*

These exhibit acid properties, like those denominated *mineral acids*, composed of the grouping of the atoms of some metal for a base with atoms of oxygen. Hence these mineral acids are described as having a *single* base in contradistinction to the preceding acids, composed of a compound base. The former have for this reason been called by chemists, "acids with a simple *radical;*" and the latter, "acids with a compound *radical.*" The term "radical," has a figurative reference to the *root* of the acid.

Every kind of vegetable acid and alkali is constituted of compound radicals, as above described; and for this reason Liebig has defined organic chemistry to be "the chemistry of compound radicals." This figurative use of the term "radical," is adopted to represent certain compound groupings of atoms into organic formations, which combine chemically with various simple elementary substances, and may be again obtained by the chemical decomposition thereof in the same state, as if they were really simple substances themselves, and incapable of decomposition into more simple parts.

Inorganic action commonly produces the groupings of only two kinds of elementary atoms with each other; but Organic action produces a more complex arrangement of groupings of two or more atoms of one kind of elementary substance with numerous variable proportions of atoms of other kinds of substances.

It has just been noticed that a variation in the grouping of only a few atoms, more or less, in the organic formation of wood, grains of wheat, rye, &c., constitutes all the discoverable differences of the constitution of substances that possess the properties of food and fuel, as well as other important characteristic properties. So it may be noticed that further variations in the groupings of a few atoms, more or less, of the *same* kinds of elementary matter, produce essentially different chemical properties in the resulting vegetable organic formations.

With every accession of an additional atom, there must ensue a difference of polarized arrangements of them, and a consequent difference in the propagation of the electro-dynamic action therefrom, as is exemplified in the following Table.

By the successive additions of 2 atoms each, of carbon and hydrogen to the fixed number of 4 atoms of oxygen, as is practically effected by the powerful action of solar excitation on the organs of living plants, and by the subsequent transmutations of their vegetable organic formations by the organs of animals, a very interesting series of organic products are the results. These are well worthy of inspection, as demonstrating the very extraordinary changes of powers of propagating electro-dynamic action, constituting *chemical* properties of ACIDS, which solar excitation is capable of inducing in groupings of atoms of carbon, hydrogen, and oxygen, through the instrumentality of the organs of plants.

TABLE

Of various characteristic properties of compound substances, produced by the electro-dynamic action of the sun in GROUPING ATOMS, *through the instrumentality of the organs of plants.*

NO.	ATOMS OF CARBON.	ATOMS OF HYDROGEN.	ATOMS OF OXYGEN.	COMPOUND SUBSTANCES PRODUCED.		
1	4	4	4	Hydrated Acetic, or Vinegar,		Acid.
2	6	6	4	Meta-cetonic (Burnt Sugar),		"
3	8	8	4	Butryic (Butter), an	oily	"
4	10	10	4	Valerianic,	"	"
5	12	12	4	Caproic.	"	"
6	14	14	4	Oenanthylic,	"	"
7	16	16	4	Caprytic,	"	"
8	18	18	4	Pelargonic,	"	"
9	20	20	4	Capric,	"	"
10	*	*	*			
11	24	24	4	Lauric (Bay berry Tallow),	"	"
12	26	26	4	Cocinic (Cocoa-nut oil),	"	"
13	28	28	4	Myristic (Nutmeg oil),	"	"
14	*	*	*			
15	32	32	4	Palmitic (Palm oil),	"	"
16	34	34	4	Margaric (Fat),	"	"

The series wanting in the above Table, Liebig remarks, will probably soon be made up by future discoveries.

It will be perceived, on examining the preceding list, that the first compound is common vinegar, which manifests no oily character. The second is of an intermediate character between vinegar and oily matter, forming a perfect connecting link between vinegar and butter. The third of the series is the oily matter of butter; and the remainder are vegetable oils, or fatty matter.

There is a very essential difference between the first named organic compound, *vinegar*, and the last named one, animal fat: yet there is a gradual shading off in these distinctive characteristic properties, between each one of them and those immediately preceding and following it on the list.

So by successive additions of an atom of oxygen to a grouping of 4 of carbon and 2 of hydrogen, the different compounds recognized as *Malic acid*, or apple juice, *Tartaric acid*, or cream of tartar, and *Formic acid*, a powerful acid found in the bodies of ants, are found severally produced.

Vinegar, it is familiarly known, is artificially produced by the partial chemical decomposition of vegetable compounds. Apple juice, containing carbon 4, hydrogen 2, oxygen 4 atoms, during the process of fermentation, gains 2 atoms of hydrogen, to constitute the new grouping of 4 atoms of each of these kinds of atoms, as stated in the preceding Table. If not arrested in this stage of the recoil of the atoms from their constrained static condition of grouping in vegetable organic formations, the compound gradually becomes united with more atoms of oxygen of the surrounding air, until it regains its natural static condition of carbonic acid gas and water; the former of which contains 16 atoms of oxygen to 6 of carbon, and the latter 8 atoms of oxygen to 1 of hydrogen.

This gradual recoil of organic formations to their natural static conditions, constitutes the phenomenon denoted by chemists as *Fermentation*, which will presently be considered.

In the composition of most kinds of vegetable organic formations, more or less of the atoms of nitrogen are found chemically combined or electro-mechanically grouped together, as denoted in the Table at page 150. When such organic formations are left to recoil from their constrained static conditions to their natural static conditions by the slow process of fermentation, at the instant of the reunion of the atoms of the hydrogen with those of the oxygen of the air during the nascent state of their return to water, some of the atoms of the hydrogen become electro-dynamically grouped with the atoms of nitrogen (whilst these are being grouped with atoms of the oxygen of the air), in the several relative ratios of 1 atom of nitrogen to 2 atoms, to 3 atoms and to 4 atoms of hydrogen. By this union are produced *three* very remarkable kinds of compound substances, chemically denominated *Amide*, *Ammonia*, and *Ammonium;* popularly known as the Salts of Ammonia, or salts of hartshorn.

Although the grouping of 1 atom of nitrogen to 3 atoms of hydrogen, constituting ammonia, may be found naturally existing in the atmosphere, and may constitute a portion of the food of plants, like carbonic acid gas, yet this fact does not prove it to be an Inorganic formation, in a natural static condition. On the contrary, the compound substance, Ammonia, is found prone further to recoil to ultimate natural static conditions of groupings with other kinds of elementary atoms. Ammonia, therefore, exists in a constrained static condition, intermediate between organic and inorganic formations. To this fact may probably be ascribed the extraordinary adaptedness of ammonia of *guano* to become regrouped into vegetable organic formations, and the consequent value of this article of commerce as a manure.

Liebig remarks that there is a peculiarity in the mode in which the chief elements of organic nature are combined together. This peculiarity is precisely what is intended to be designated by the term, *constrained* static *conditions of groupings of atoms*, which we have so frequently employed in describing the states of relative rest of atoms of Organic formations.

Of however many constituent kinds of atoms chemical compounds may be composed, they are held grouped together by electro-dynamic action, instead of "Inherent Chemical Affinity." This is manifest from the primary law of Chemical Combinations, which establishes that "every compound is assumed to be binary; one element, or set of the elements, being *electro-negative*, and the other *electro-positive*, the latter representing the *base*, and the former the salt radical."

In every case of the chemical change of the groupings of atoms from one combination to another, there is developed chemical action; and so in every case of the mechanical change of the groupings of atoms, from one static condition to another, there is developed electro-mechanical action, precisely as affirmed by Professor Graham; "any theory of combination would be incomplete, which did not provide in the constitution of both elementary and compound bodies, for that propagation of *chemical action at a distance*, which is witnessed in the voltaic circle."

It has been affirmed, as a popular chemical doctrine, that "no change of properties can occur without a change of composition." There must be an addition or subtraction of some of the component atoms of a body to change its characteristic properties. But it has been found that "Heat exerts a powerful influence over chemical phenomena."*

In order, therefore, to sustain the preceding chemical law, it becomes necessary for chemists to admit "heat to be a chemical constituent of bodies." This assumption adds still more to the complexity of the present chemical theories.

The *passive* state of existence of various kinds of substances to chemical action, which may be imparted to them at pleasure by the contact of other particular kinds of elementary substances, is an impressive lesson, demonstrating that chemical phenomena of decomposition are incidental effects, produced by contingent external causes; and that consequently Chemical Action is not an inherent property of elementary atoms. The recoil of the atoms of zinc takes place with increased energy on being connected with a plate of copper.

When a readily decomposable metal, immersed in an acid liquor, is brought into association with another more readily decomposable metal, as when iron is used as a substitute for the copper or platinum plate of the battery, the predominating tendency of the atoms of the zinc to recoil to their natural static conditions, electro-polarizes the groupings of the atoms of the iron so effectively, as to prevent the least development of its chemical decomposition, even when immersed in nitric acid. But if the zinc become coated with oxide so as to impede the free access of the atoms of the acid liquor, and its consequent recoiling, then the zinc, in turn, serves like a copper or platinum plate to receive the propagation of the electro-dynamic action from the iron plate, which becomes "chemically" decomposed, as chemists affirm; but electro-mechanically, as the preceding facts warrant us to affirm.

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* Liebig's & Gregory's edition of Turner's Chemistry, page 20.

By bringing together groupings of atoms of inorganic formations with those of organic formations, to facilitate the reciprocal propagation of electro-dynamic action and reaction between these commingled groupings of atoms, modifications of organic and inorganic actions occur, which impart to the resulting compound bodies infinitely varied characteristic properties. As observed by Stöckhardt, "thousands of such new combinations have been produced within the last twenty years. Our posterity will probably count them by millions."

Some chemists have supposed they have discovered that several different kinds of compound substances are constituted of equal proportionate parts of the same kinds of elementary atoms. They have denominated such bodies ISOMERIC, as has been previously stated at page 92. By analyzing starch, sugar, and wood, they have considered that they are alike each composed of groupings in the relative ratio of 6 atoms of carbon, 5 of hydrogen, and 5 of oxygen. Hence they have urged that identity of composition is not a cause of identity of characteristic properties; for it is well known that starch, sugar, and woody fibre exhibit very different characteristic properties.

This argument corroborates the principle which has been sustained, that the characteristic properties of matter are ascribable to the mechanical groupings of atoms into visible magnitudes. The same kinds of atoms may be so grouped interchangeably with each other, as appears by the preceding statement, as to exhibit different characteristic properties.

As all inorganic and organic formations have been traced in the preceding investigations to the continuous circulation of electric currents about terrestrial atoms at insensible distances, producing their electro-polarization, and as it has been shown at page 464, figure 114, that slight changes in the relative arrangements of the equatorial and polar parts of such atoms produce all the difference between an *active* pole and an *inactive* pole of the same atoms of steel, we can imagine no other reasons than these for the difference of the action propagated by the atoms of wood, sugar, starch, and other isomeric bodies. This idea is also consistent with the supposition, that all the distinctive characteristic properties of matter are ascribable to the diversified modifications of the electro-dynamic action propagated thereby in the static and dynamic forms, which have been recapitulated in referring to the nerves of sensitive beings, considered as electroscopic tests of *colors*, *taste*, *odors*, *temperatures*, &c.

The specific object in introducing the notice of the preceding facts, is to show, that the electro-dynamic action of the sun on the organs of living plants is capable of imparting to an infinite variety of combinations of less than half a dozen kinds of atoms into organic formations, decisive characteristic powers of propagating actions and reactions. To the consideration of these groupings the whole grand subdivision of the science of Organic Chemistry is appropriately devoted; and a similar grand subdivision of the science of Mechanics will be correspondingly appropriated, under the title of Organic Mechanical Action.

In the preceding investigations, the organic action propagated through the mechanisms of the organs of plants, whilst subjected to solar excitations, has been considered as antagonistical to inorganic action. Organic formations have been deemed to be so many specific kinds of groupings of atoms reduced to constrained static conditions, like bended springs, from which such groupings recoil to their natural static inorganic conditions, when relieved of the overpowering organic excitation.

What we have considered in mechanical philosophy as "static conditions" of groupings of atoms, sustained by continuously propagated and counterbalanced electro-dynamic impulses, have been denoted in chemical philosophy by the term "chemical combinations;" and what has here been considered as the dynamic action resulting from every change of grouping of atoms from one static condition to another, has been denominated by chemists, "chemical actions and reactions."

It is the province of the science of chemistry to discover and arrange systematically all the classes of facts which have relation to the changes of the grouping of atoms into various "combinations," and to treat of the characteristic properties developed by such groupings whilst in *combination*, and whilst exerting action in their transition from one state of combination to another. It is the province of the science of mechanics to investigate the causes of the impulses which move atoms, and which become propagated between atoms and masses of matter in the variously modified forms of electricity, heat, light, magnetism, cohesion, crystallization, fermentation, combustion, and animal motive power.

By confining chemical and mechanical science each to its appropriate province of research and investigation, there can be no competition for claims to precedency of rank, unless it be in more rapidly accomplishing the great purpose of advancing human knowledge by truthful demonstrations.

The investigation of the subject of "Chemical Action as a Source of Natural Motive Power," has been anticipated in the preceding synthetical details, which will be found at pages 169 and 270, in the chapters on Dynamics, as originating from the electro-dynamic action of the sun, and propagated through the mechanisms of organic and inorganic formations.

INORGANIC REACTION DEVELOPED BETWEEN GROUPINGS OF ATOMS ON RECOILING FROM THEIR CONSTRAINED STATIC CONDITIONS OF ORGANIC FORMATIONS TO THEIR NATURAL STATIC CONDITIONS OF INORGANIC FORMATIONS, PRODUCING THE PHENOMENON OF—

"FERMENTATION."

The principles of the phenomenon of fermentation have been anticipated in treating of the grouping of atoms into vegetable and animal Organic Formations. It has been shown at page 28, that the Inorganic Fluid Formations of water, air, and carbonic acid gas, composed of the four "organic elements of carbon, hydrogen, oxygen, and nitrogen, play a most important part in the mechanics of nature. They subserve the purpose of incessantly vibrating from natural static conditions of Inorganic formations to the constrained static condition of Organic formations, whilst subjected to solar excitation, in connection with the mechanisms of plants; and of subsequently recoiling, like deflected springs, to their original natural static condition, on being relieved of the paramount constraining power, and allowed freedom of motion in fluids. These facts are adverted to at page 99; and the process of this gradual recoil has been also adverted to in describing the exciting influence of vernal solar action and vernal showers on the farinaceous matter of the germs of plants, page 102.

The preceding principles differ essentially from the opinions advanced by eminent writers on this subject. To afford the reader a view of the doctrines now adopted to explain the phenomenon of Fermentation, the views of some of the most popular chemists will be here briefly recapitulated.

There are two theories of the action of Fermentation. "According to Berzelius, it acts by contact, catalytically; that is, by contact with the sugar, it somehow causes the latter to be decomposed, just as sulphuric acid in contact with alcohol, causes it to be resolved into ether and water."

"The other theory is that of Liebig. He observes, that, in innumerable cases, the contact of a body in a state of change, or of motion in the particles, causes a state of motion in the particles of another body in contact with it, and thus produces decomposition."

"Now, when the ferment or exciting body comes into contact with the sugar, the motion of the particles of the ferment being mechanically communicated to those of the sugar, which are held together in an unstable equilibrium, that equilibrium is destroyed, and the particles of the sugar assume new forms of combination, in this case alcohol and carbonic acid, which are more stable under existing circumstances."

"Such is Liebeg's theory of fermentation; and it must be admitted, in the present state of our knowledge, to explain all the phenomena in a scientific manner."*

Again, it has been supposed that "the molecules of the class of compounds to which sugar belongs, are only contained in combination, by virtue of the *inertia* of their elements, and every change in the equilibrium of these elements forces them to attract each other in a different order."

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* Gregory and Liebig's 8th edition of Turner's Chemistry, page 690.

From the visible movements of the particles of fermenting bodies, several chemists have been disposed to ascribe them to animalculæ, endowed with vitality. Mitscherlich supposes the existence of a species of infusoria.

Fermenting molecules always give out particles of carbonic acid gas during the process of their mechanical recoil, or chemical decomposition. A reaction necessarily ensues from the expansion of the nascent carbonic acid gas. This moves the atoms of the fermenting mass; precisely as the small shell termed "the eye-stone," will appear to move and have life, when placed in a cup of vinegar. The bubbles of carbonic acid gas of this small decomposing sea-shell cause it to become partially unplifted, and moved, which test of LIFE was once resorted to by the unskilful, to prove the ideal value of this appliance for removing specks from beneath the eyelid. The supposition that fermentation is due to animalculæ may also have originated from the fact of their appearance in putrefying masses. In this case a contingent *effect* produced, appears to have been mistaken for a *cause*.

The substance commonly used for inducing the process of fermentation in inorganic formations, is the already fermenting froth of beer vats. The movements and excitation of this fermenting mass, induce the commencement of the same process among the grouping of the atoms of vegetable matter with which it is commingled.

The kinds of elementary atoms usually found to constitute the most readily fermentable *Yeast*, are the four organic elements (page 28), in the following proportionate parts, as tested by several chemists.

		Parts.	
Carbon, - - -	47·	100	A little sulphur and phosphorus are included with the oxygen.
Hydrogen, - -	6·6		
Oxygen, - -	36·4		
Nitrogen, - -	10·		

All organic formations which contain a considerable proportion of atoms of nitrogen grouped therewith, are found to be in a more constrained static condition, and more prone readily to recoil to their natural static condition, than the formations which contain no atoms of nitrogen.

The essential exciting quality in yeast, has been found principally to consist of a small portion of the substance denominated by chemists DIASTASE; of which 1 part is sufficient to excite 2000 parts of a solution of starch, and to resolve it into another peculiar form of temporary static condition of grouping, denominated DEXTRIN. This latter substance resembles gum arabic, and is known as "British Gum."

The process of the recoil of the atoms of organic formations, in passing from one stage of grouping to another, to regain their natural static condition of carbonic acid gas and water, has been arrested by chemists in nearly a dozen different stages, so as to exhibit an equal number of distinct kinds of substances, each differing from the others by exhibiting some peculiar characteristic property. They have been arranged in the following order of processes:—

Dextrinic,
Glucose,
Vinous,
Lactic,
Butyric,
Mucous,
Acetous,
Putrefactive, &c.

The gradual progress of the recoil of groupings of atoms of vegetable organic formations, by the process of Fermentation, as above stated, is accomplished on a great scale in breweries. The starch of the barley is converted, successively, into the following substances:—

Starch of barley, flour, &c., contains,	Carbon.	Hydrogen.	Oxygen.
1. Sugar,* - - - -	12	12	11
2. Alcohol, - - - -	12	11	11
3. Acetic acid, - - - -	4	6	2
4. Original natural static conditions of groupings,	4	3	3

A certain degree of excitation of the temperature between 60° and 80° of Fahr. scale, is necessary to excite and maintain the process of fermentation. This specific degree of heat, like that of ignited bodies applied to kindle combustible fuel, is required to *begin* this species of slow combustion in a moist state. The presence of the atoms of oxygen of the air is also necessary at the commencement of the process, as in the combustion of fuel; for, according to Liebeg, grape juice "may be kept unchanged any length of time, if preserved from contact with the air." Hence, it has been argued that the recoiling process of fermentation is not absolutely *spontaneous*.

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* Turner's Chemistry.

The first symptom of the commencement of the process of fermentation, is the movement of the fluid atoms of the mass, and the appearance of bubbles of carbonic acid gas.

The development of mechanical action becomes manifested by the bursting of the vessels confining the fermenting substances. As a preliminary preparation for the investigation of this subject, the familiar process of the fermentation of *bread*, which has been figuratively termed the *staff of life*, will be considered.

As yeast, after undergoing the saccharine and vinous fermentation, becomes still further decomposed by the subsequent process of the *acetous* fermentation, and by the finally destructive *putrefactive* fermentation, it becomes a matter of importance in household economy to make use of such yeast only as is freshly made; for if it be suffered to go through with the *vinous* fermentation, and to enter upon the *acetous* stage before being used, this *acetous* fermentation will be simultaneously induced. Sour bread must unfailingly be the result, as well as sour faces of those hungry expectants who rely for their daily supply of savory food on the skill of a careful baker.

In order to excite this fermentation in an effectual manner, recourse is had to the use of excited ingredients. This practice is in accordance with "Inductive Excitation," explained at page 282, where one excited body brought near another induces similar excitation. One part of fermenting malt liquor is found to be capable of exciting fermentation in 100 parts of flour. But a portion of the fermenting flour itself, however, is commonly used to excite fermentation in other fresh masses of flour; in which case it is termed "leaven." The leaven being abstracted from a mass of flour whilst undergoing fermentation, it is manifest from the preceding remarks, that if kept even for a short time, it rapidly progresses into the acetous stage of fermentation.

In order to check the fermentation before it runs into the acetous stage, it has been adopted as a useful practice to dry the leaven, which in this case has been kept for sale in shops under the name of "portable yeast."

Published accounts render it probable, that the original ferment of the bread made throughout Spain and Portugal, was first obtained many centuries ago in Carthage, from whence the use of *raised* bread was introduced into Europe. The process of fermentation has ever since been continually sustained there, like the vestal fire, which was never suffered to expire whilst under the watchful care of the Roman virgins.

The development of the bubbles of carbonic acid during the partial decomposition of the kneaded mass, produces the light spongy cellular texture of the bread. A similar *appearance* of lightness is produced by artificially commingling acid and alkaline solutions in the mass of moistened flour. But the preceding observations are sufficient to convince every consumer of bread, that the properties of the fermented flour are very different from those of the chemically inflated flour, as has been previously referred to in treating of the decomposition of the farinaceous matter serving as food for the germs of the plants, from which this very farina or flour is extracted. It was there shown, that in order to enable the germ to absorb as its appropriate food the little store of farina, in connection with which it exists, that the grouping of the atoms must be first reduced to a moistened pulpy state, and excited to ferment by vernal showers and vernal sunshine; and that during this relaxation of the organic action between the particles, the vital powers of the germ are enabled to control the transfer of them into the organizations of its own body.

Chemical analysis of fermented starch of wheat shows that a considerable part of it becomes converted into sugar by the above stated *saccharine fermentation*. By the chemical process of filling the dough with bubbles of carbonic acid, the advantage of this *saccharine* or sugar-producing fermentation is not available, neither is the product so well prepared to become assimilated by the animal organs, analogously to the assimilation by the organs of the germ of wheat contained in each original grain, as above recapitulated. Hence it is argued, that the process of the fermentation of wheaten bread, which has been practised from the earliest historical records, is really founded on good and sufficient scientific principles, for which the modern use of chemical processes is an absolute departure.

By subjecting the fermenting mass above described to a process of *distillation* at the termination of the vinous process of fermentation, the half-resolved grouping of organic formation is obtained, constituting the article of commerce known as ALCOHOL. In further illustration of the more ready assimilation of the groupings of organic formations of food into the arterial circulation, and of its more ready facility of complete decomposition by combustion in the lungs for producing the more speedy development of animal motive power and nervous excitation, may be cited the use of ALCOHOL, the third product of fermenting vegetable organic formations of starch. The speedy and violent excitation of the animal system resulting from this nearly resolved grouping of organic formations is unfortunately too well known to require description.

It appears that the atoms of this compound become resolved, during the process of fermentation, into such a constrained static condition, as to yield readily to the inorganic recoiling reaction. It may even be burnt as a liquid *fuel* in a spirit lamp, and thus speedily resolved into its natural static condition of carbonic acid gas and water.

When incorporated into the blood without being reduced to the next lower product of *acetic acid*, and burnt in the lungs, the carbonic acid gas and water are passed through the thin arterial membranes, by the mode of permeation which has been practically illustrated by experiments with sheets of parchment and of India-rubber, and denoted by the terms EXOSMOSE and ENDOSMOSE.

If the development of animal motive power, and the propagation of electro-dynamic action through the nerves of the brain originate, as we shall presently have occasion to show, from the combustion of the organic carbon of the blood within the vessels of the lungs, and the expulsion of the gaseous products of this combustion by the *exosmose* action, then we may arrive at the philosophy of the entire suspension of all voluntary animal motive power, and also of the propagation of action through the nerves to the brain, by breathing ether and chloroform. By applying to the *external* coatings of the blood-vessels of the lungs a more readily decomposable grouping of organic formation than that of the blood, as is effected in BREATHING ETHER and CHLORO-

FORM, a reversed reaction must ensue, which must also induce a reversal or counteraction of all the functions of animal motive power, and also of the propagation of electro-dynamic action through the nerves to the brain. By thus reversing the direction of the propagation of electro-dynamic action through the nerves, it appears probable that their powers of suspension are suspended; there consequently ensues a suspension of the functions of the nervous system and of the muscles.

That ether is an organic formation more nearly reduced to its final natural static condition than the alcohol from which it is manufactured, is manifest from the fact of its artificial production by the contact of the sulphuric acid therewith, in the same manner as starch is now actually converted into sugar, which is sold as an article of commerce, by means of a similar treatment with the same acid. And chloroform is also similarly produced by modifying the constrained static condition of the groupings of the atoms of alcohol by the union therewith of atoms of chlorine.

These facts will be reverted to when we come to treat of *animal motive power.*

FURTHER INORGANIC REACTION DEVELOPED BETWEEN GROUPINGS OF ATOMS ON RECOILING FROM THEIR CONSTRAINED STATIC CONDITIONS OF ORGANIC FORMATIONS TO THEIR NATURAL STATIC CONDITIONS OF INORGANIC FORMATIONS, PRODUCING THE PHENOMENON OF—

"ACETOUS FERMENTATION."

The next stage of the gradual recoil of atoms from their groupings as organic formations to those of carbonic acid gas and water, is termed the *Acetous*, or acid-producing fermentation. Vinegar is an acid commonly obtainable by the fermentation of wine, its name being derived from the French words denoting *sour wine.*

After the farinaceous matter of the seeds of barley, wheat, rye, &c., has passed through the first stage of fermentation, which has just been described, if the progress of its further recoil be not artificially arrested by an increase or decrease of temperature, as by drying, baking, or freezing, the acetous stage follows in course.

As fermenting yeast induces the excitation of the same process in a mass of the same materials not in a state of fermentation, so after passing into the second stage of gradual recoil, it will similarly induce the excitation of the same process of acetous fermentation. Thus a mass of food in the stomach may be caused to undergo acetous fermentation, where the functions of this organ are impaired, as occurs in dyspeptic persons. This phenomenon appears to be resolvable into the propagation of a similar electro-polarization of atoms from atom to atom throughout the mass.

Although alcohol, one of the organic formations, arrested artificially by the process of distillation in a half-recoiled stage, will remain unchanged under favorable circumstances, and when kept in close vessels, yet if excited by being mixed with fermenting yeast, it speedily runs out its course of final recoil to carbonic acid gas and water. But when alcohol has passed into the stage of acetic acid, it then constitutes a pure transparent vinegar, which retains still a considerable degree of antiseptic power for preserving vegetable organic formations immersed therein, as familiarly known in the practice of *pickling*.

But the grouping of atoms of alcohol admits of being electro-polarized speedily by a species of half combustion on the wick of a lamp, around which is wound a spiral coil of fine platinum wire. The atoms of hydrogen of the alcohol become united with oxygen where it comes in contact with the wire, in the modified form of a slow combustion, which is maintained continuously and the wire kept in a red-hot state, until all the alcohol becomes drawn up into the wick, and passed off therefrom in vapor.

If this vapor be collected in a suitable receiver, and condensed therein, it will be found to constitute acetic acid.

By this process is rapidly accomplished the result of a partial combustion of the alcohol, accompanied with the development of the electro-dynamic action in the modified form of heat and light. By the regular process of fermentation a much longer time would be required to accomplish the same result, and the propagation of the electro-dynamic action, in the modified form of *heat*, would be less perceptible, and in that of light, not sufficiently intense to act on the nerves of the eye.

In the process of the recoil of alcohol to acetic acid, it appears that three atoms of the hydrogen disappear from the grouping, and one atom of oxygen is added, as denoted by the chemical formula for hydrated acetic acid = carbon 4, hydrogen 3, oxygen 3. The three atoms of hydrogen probably become united with the oxygen of the acid in recoiling directly to their natural static condition of water, rendering this change of grouping a regular process of *slow combustion.*

An expeditious process of converting alcohol into vinegar has been practised in Germany, which produces a beautifully transparent article for pickles. It is also beautifully illustrative of the science of the recoil of organic formations by successive stages to their final static conditions of groupings. Black platinum powder, when kept moistened with alcohol, continues red-hot, like the spiral wire about the wick of the alcohol lamp; and the vapor which rises is regularly condensed upon the sides of the receiving-vessel, and descends in pure pellucid trickling streams of acetic acid.

As the process of converting the organic matter of cider, wine, malt-liquors, &c., into vinegar, is essentially a species of slow combustion, it is, of course, as necessary to provide a free access thereto of the oxygen of the air, as to organic fuel consumed in a furnace. To increase the extent of surface of the fermenting liquors exposed to the oxygen of the air, to the greatest possible degree, it is usual to cause them to trickle over shavings, carefully arranged with this view in large apartments kept at a warm temperature.

Even the solid organic formation of wood, in its recoil to the natural static condition of carbonic acid gas and water by the process of combustion in a furnace, may have its progress of recoil arrested at the proper point, so as to resolve it into acetic acid, termed PYROLIGNEOUS ACID. It is only necessary to place green wood in iron retorts, kept red-hot; a partial combustion of the wood takes place, similar to that of the alcohol in the wick of the lamp, evironed by the spiral coil of platinum wire. The portion of the wood is distilled in a dark-colored liquid, which constitutes a very cheap kind of acetic acid, much used in the chemical processes of calico-printing.

The acid is commingled with other recoiling organic products of this destructive distillation, such as creosote and tarry matter.

These facts will be sufficient to represent the principles of the regular recoil of the atoms of organic formations through successive stages of groupings, to the last and final stage of PUTREFACTION.

FINAL RETURN OF ORGANIC FORMATIONS OF ALL VEGETABLE AND ANIMAL SUBSTANCES TO THEIR NATURAL STATIC CONDITION OF CARBONIC ACID GAS AND WATER, BY THE PROCESS OF—

"PUTREFACTIVE FERMENTATION."

The final recoil of groupings of atoms from their constrained static conditions of organic formations to their natural static conditions of carbonic acid gas and water, presents the phenomenon of *Putrefaction*, denominated by Liebig, *Eremacausis*, as before stated.

Although this final process is essentially a continuation of one general system of recoil, yet, as the separation of the constituent atoms of the putrefying bodies exhibits distinct and peculiar characteristic properties of offensive odors, produced by their electro-dynamic action on the nerves of smell, and also new groupings of the separating atoms in the static condition of ammonia, phosphuretted hydrogen, and sulphuretted hydrogen, as well as of water and carbonic acid gas, a distinct classification has been assigned for the consideration of the phenomenon of Putrefraction.

After the paramount Organic action of life-power has ceased to control the groupings of atoms into organic formations, they immediately become subjected to the conditional control of the antagonistic Inorganic reaction. But the rapidity of their recoil to their natural static conditions of carbonic acid gas and water is modified by circumstances of the varying propagation thereto of the electro dynamic action of the sun. By concentrating the partial solar excitation on vegetable and animal organic formations, by means of a concave mirror, or convex lens, they become speedily reduced to their natural static conditions; and by averting the same cause of excitation of electro-polarization, by freezing, they become crystallized and unchanged for indefinite periods of time, like the remains of the flesh of the antediluvian mammoth, discovered in the glacier of Siberia. A particular range of excitation of temperature, between 80° and 100° of Fahrenheit's scale, is most favorable for inducing putrefactive fermentation.

The recoil of the groupings of atoms both of organic and inorganic formations, appears to be remarkably accelerated by the presence of atoms of nitrogen. There are peculiar functions accomplished by the presence of this particular kind of atoms, which are of so important a character as to require a special notice.

The functions of the atoms of nitrogen appear to be of a diluent character. They serve to weaken the intensity of electro-polarizations of the other atoms, with which they are combined in fluid and solid masses. The commingling of more than three-fourth parts of nitrogen in the atmosphere of the earth, serves manifestly to neutralize the electro-polarizing powers of the oxygen, which, if pure, would cause even the iron bars of the grates of furnaces to burn more brilliantly than the fuel which they are commonly used to support. When the atoms of nitrogen are combined with the several other kinds of atoms united together in one common arrangement of grouping, they serve like the spherical groupings of water, as it were to dissolve their connection, by neutralizing the electro-polarization which binds them together in a mass; as the solid component atoms of salts, sugar, &c., become freely movable in solutions.

This result being accomplished by the presence of atoms of nitrogen, then the other atoms grouped together with them become more readily movable, in obedience to the impulses of their respective natural electro-polarized forces.

It may be a question whether this explanation is a true exposition of the principle involved in this discussion; yet it serves to account for the facts developed. All organic formations containing nitrogen, are found prone to recoil rapidly to their natural static conditions, by the process of fermentation putrefaction or eremacausis, and combustion. The presence of an extraordinary quantity of nitrogen in yeast, and in animal formations (see table at page 150), in the nitrates of potash, saltpetre, and in the nitrates of silver, mercury, and of various other substances, constituting "fulminating," or "detonating" powders, are eminent instances of this proneness to recoil rapidly and violently, from constrained to natural static conditions of groupings.

The association of atoms of nitrogen, even in living bodies, so remarkably facilitates this recoil in the modified form of putrefaction, that frequent instances are recorded of the excitation of the putrefactive process, even in despite of the powers of vitality, as occurs in mortification of wounds. In the dissection of putrefying dead bodies by surgeons and students, if the putrefying morbid matter enter the system through the absorbent vessels of the hands, when accidentally cut by the dissecting knife, an excitation of the putrefactive fermentation is induced in the circulating blood, which no medicines or appliances of art can arrest; and death consequently ensues.

But so powerfully active are the chemical powers of the gastric fluid elaborated in the stomach, particularly of dogs and vultures, that the process of putrefaction becomes instantaneously arrested therein.

It appears that the vital or organic powers of the stomach are enabled to take advantage more readily of the assimilation of the neutralized substances containing nitrogen, constituting the elements of food, whilst they are in transition from the fixed state, induced by the Organic action, and on the point of yielding to the Inorganic reaction, as has been previously noticed in treating of the germination of plants. At this precise favorable conjuncture, the Organic action of living vegetables, and of animal mechanisms, are adequate to controlling the propagation of the electro-dynamic action to reproduce new arrangements of the same molecular organic groupings into new organizations of vegetable and animal bodies.

But even the organic action of the mechanism of the human stomach is inadequate to controlling the recoiling reaction of inorganic forces, in extreme cases of putrefying food introduced therein. It cannot modify it into chyle and healthful circulating blood. The same recoiling process becomes propagated to the blood, and to the muscles abounding in nitrogen, which yield to this paramount prevalence of Inorganic reaction. Liebig states that instances have occurred where putrefying sausages, consumed as food, have produced a wasting away of the patient, until "he dries to a mummy, and finally dies." These cases exhibit singular instances of the protracted struggle for mastery, of the Organic and Inorganic powers.

From the fact that the *virus* is propagated by inoculation into the circulating blood, and that the plague, and other morbid conditions of the functions of vitality, are similarly propagated by means of contact, the supposition has been entertained that "morbid virus exhibits such a strong similarity to the action of yeast upon liquids containing sugar, and gluten, that the two processes have long since been compared to one another."

The preceding considerations seem to exhibit the admirably nice balances of static and dynamic conditions of the antagonistical Organic and Inorganic actions and reactions, whereby the life-power maintains its sceptre of control by modifying the propagation of the electro-dynamic impulses, originating from solar influence. It exhibits truly a "perpetual struggle between life and death," with the certainty of the final physical triumph of the latter. We thus arrive at the sad philosophical truth, that all the groupings of atoms into inorganic formations of intellectual human beings, are destined to become resolved into invisible gas and vapor, leaving only the solid remains of a handful of lime-dust in the bottom of a grave.

But whilst this perpetual decadence of all vegetable organic formations is going on upon the crust of our planet, renovation and fresh life, on the other hand, is perpetually springing forth in the renewed modifications of the propagation of solar electro-dynamic action on the germs of living plants. The freshness of youthful buds follows the decay of the mouldering leaf, as if the same atoms were regrouped therein; and even the loathsome mass of the putrefying animal body, in the economy of nature, is not permitted to become wastefully diffused to the winds of heaven; for microscopic animalculae unaccountably spring into existence, and are soon found revelling therein. They are speedily succeeded by other generations and species, extending without stint the principle of the development of Organic action, and with it the enjoyments of sentient living beings.

INORGANIC REACTION DEVELOPED BETWEEN GROUPINGS OF ATOMS ON RECOILING FROM THEIR CONSTRAINED STATIC CONDITIONS OF ORGANIC FORMATIONS, TO THEIR NATURAL STATIC CONDITIONS OF INORGANIC FORMATIONS, PRODUCING THE PHENOMENON OF THE—

EXPLOSIVE FORCE OF GUN-COTTON AND GUN-POWDER.

The presence of atoms of nitrogen in organic formations has been repeatedly referred to, as serving to neutralize the intensity of the propagation of Organic action, sustaining organic formations in their various fixed states of solidity, as balanced antagonistically against the recoiling Inorganic reaction.

In the above described process of Fermentation, the atoms of nitrogen are found to be naturally grouped with those of carbon, hydrogen, and oxygen, in various vegetable and animal organic formations. The same result of a more rapid change of electro-polarization, and of the recoil of Inorganic impulses, producing an *explosive* scattering of the component atoms, is found to occur even when atoms of nitrogen are *artificially* combined with groupings of atoms of organic formations. This may be readily accomplished by immersing a lock of cotton for about two minutes in fuming nitric acid, and by then squeezing out the surplus acid, and rinsing the cotton in pure water.

After this operation, the fibres of the cotton appear very little altered; but by chemical analysis, the following change of the relative groupings of the atoms has been discovered:

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.
Pure Cotton, ...	44·50	6·10	49·40	0·00
Gun Cotton, ...	27·43	3·54	54·77	14·26

By the accession of about 14 per cent. of atoms of nitrogen, and of 6 per cent. of oxygen, the vegetable organic formation of cotton, which previously was found to recoil tardily during the process of combustion to its natural static condition of carbonic acid gas and water, and only by the aid of a continuous supply of atoms of oxygen from the open air, is found to become reduced to so delicately balanced an electro-static condition, as to yield instantaneously to the Inorganic reaction. It explodes with extraordinary violence, even when confined in the iron chamber of a cannon, developing the usual electro-dynamic phenomena of light, heat, and of most intense impulses of mechanical force.

Saw-dust of wood may be substituted for the cotton in the preceding experiment. It may be disolved in strong nitric acid, and after being diluted with water, may be obtained as a deposit of a white insoluble powder, which, on being ignited, will explode like gunpowder.

By a similar artificial union of nitrogen with vegetable manna, a compound is obtained, which is reduced to such an exceedingly delicate condition of static equilibrium of Organic and Inorganic powers, that a simple blow of a hammer is sufficient to disturb it, and to produce a detonating explosion. It may be used as a detonating or percussion powder even in preference to the nitrates of silver and of mercury for exploding gunpowder in firearms, being both cheaper and less dangerous for use. It requires for detonation a violent blow between two hard bodies, whilst it may be placed on paper and touched with a red-hot coal without producing explosion. It yields no corroding nitrous vapor when exploded, and does not change by keeping. Thus wonderfully endued with electro-dynamic properties is the delicately balanced eloctro-static union of the atoms of carbon, hydrogen, oxygen, and nitrogen, in this artificial preparation of the organic formation of manna, which constitutes an article of food, and the medium for propagating electro-dynamic action in the modified form of animal motive power.

Even the partially decomposed organic vegetable formation of pure charcoal admits of being reduced also to a similar delicately balanced static condition, by artificially bringing into union therewith nearly the same relative grouping of atoms as exhibited in the preceding table of the constituent elements of gun-cotton. By placing cotton in an air-tight iron retort, and subjecting it to sufficient heat to render it red-hot, the 6·10 per cent. of hydrogen and 49·40 per cent. of oxygen become grouped together, partly to form water, and are expelled therefrom, leaving the residuum of 44·50 per cent. of pure carbon or charcoal. In this condition of pure charcoal the atoms are reduced to a more stable static condition, from which they may be allowed to recoil during the process of combustion, wherein there must necessarily be a free access of atoms of the oxygen of the air by a gradual process of combination. It is manifest that these atoms of carbon cannot recoil to their natural static condition of carbonic acid gas unless atoms of oxygen be allowed free access to them. This is commonly and cheaply accomplished by allowing a current of atmospheric air to come in contact with the atoms of carbon through the furnace grates. But atoms of oxygen, united with other substances containing nitrogen to weaken their "chemical affinity," may be artificially introduced into contact with those of the charcoal; so that the latter may recoil to its natural static condition of carbonic acid gas and water, whilst confined in close vessels, from which the access of the air is excluded.

To accomplish this result, the substance of saltpetre, or nitre, has commonly been selected, constituted of a grouping of 6 atoms of oxygen and 1 of nitrogen, with 1 of potash. By grinding together saltpetre and charcoal, there is replaced in contact with the charcoal of the substance of cotton just referred to, the same quantity of atoms of nitrogen and oxygen, as exhibited in the composition of the gun-cotton; whereby this artificial vegetable compound of organic carbon becomes equivalent thereto, as *gunpowder*. It is capable, like gun-cotton, of instantaneously recoiling on being ignited.

To accomplish this artificial grouping of organic charcoal with atoms of oxygen and nitrogen, is the business of the manufacturer of gunpowder. The materials are brought into intimate contact by being finely pulverized and ground together.

By the presence of the atoms of nitrogen, the action of the organic carbon is reduced to a delicately balanced static condition of grouping with the atoms of oxygen. They are thus artificially furnished with a ready supply of oxygen, independently of recourse to the stock of it contained in the open air. The sulphur, used in the manufacture of gunpowder, aids the speedy combustibility of the compound by kindling at a low temperature; a result which in the gun-cotton is favored by the substitution of the atoms of hydrogen, and by the open texture of the vegetable fibre.

Gunpowder is actually a very near copy of the composition of gun-cotton, both being constituted of nearly similar groupings of atoms, and serving similarly to develope the same inorganic or electro-dynamic reaction.

Thus is traceable to the electro-dynamic action of the sun on the organs of plants, the most effective motive-power available by man for rending rocks, upheaving mountain cliffs, and projecting the most destructive missiles employed in human warfare, when this mechanical power is unhappily resorted to as a substitute for the power of reason and right, of justice and of Christian principles.

INORGANIC REACTION DEVELOPED BETWEEN GROUPINGS OF ATOMS ON RECOILING FROM THEIR CONSTRAINED STATIC CONDITIONS TO THEIR NATURAL STATIC CONDITIONS OF INORGANIC FORMATIONS, PRODUCING THE PHENOMENON OF—

"COMBUSTION."

In considering the phenomenon of combustion, we are governed by the same principles which have been developed in the recoil of organic formations by the processes termed "Fermentation" and "Explosion." The former has been denominated a species of slow combustion, and the latter has been shown to differ from the former only in regard to the *time* in which the process is accomplished, and consequently in the degree of intensity of development of electro-dynamic action.

It has been repeatedly illustrated in the preceding pages, that during every change of the groupings of atoms from one static condition to another, a resultant dynamic action produces the phenomenon of heat, light, and electricity, according as it is modified to propagate impulses to the material nerves of the intelligent beings, who necessarily have recourse to these electroscopic tests to form their judgments of the conditions of terrestrial matter.

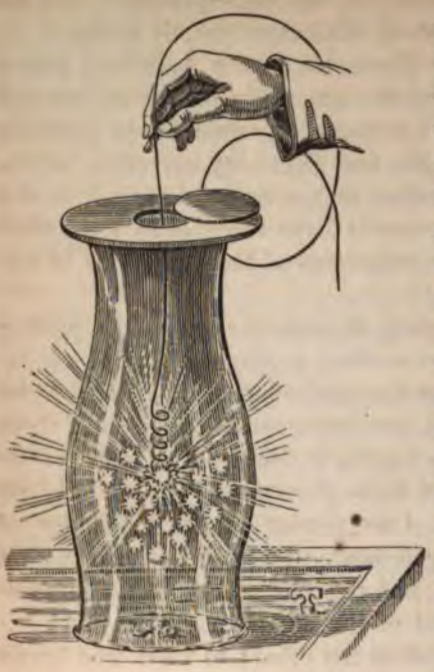
When any kind of grouping of elementary atoms, on passing from one static condition to another, propagates action simultaneously to the nerves of the eye, producing sensations of light, and to the nerves of feeling, producing sensations of heat, these concomitant phenomena are popularly denoted by the term COMBUSTION; and the cause of those phenomena is popularly ascribed to FIRE and HEAT. One portion of the groupings of atoms which becomes changed during the process of combustion has been denominated FUEL, and the other a *supporter* of combustion, although often one class of the atoms may be as much entitled to be considered as fuel as the other; as when iron burns in the vapor of sulphur.

The principal kinds of substances available as fuel are the vegetable organic formations.

The kinds of fuel usually employed for undergoing the process of combustion in furnaces, forges, and on the domestic hearth, are wood, peat, and mineral coal.

The agriculturist who plants the seeds of forest trees for the specific purpose of producing wood for fuel, has practical recourse to the organs of plants as mechanisms for modifying the propagation of the electro-dynamic action of the sun; whereby he is enabled to collect atoms of carbonic acid gas and water, and to reduce them from their natural static conditions to the temporary constrained static condition of the vegetable organic formation of woody fibres. In like manner peat is produced by the action of the sun on the organs of a particular class of plants, and mineral coal has been considered as similarly produced by antediluvian sunshine. All animal oils used as fuel for lamps consist of reorganizations of vegetable formations.

Fig. 130.



Inorganic formations of various kinds are also found to be combustible, as well as vegetable substances. Various metals reduced to thin leaves and immersed in pure oxygen gas beneath a glass, are found to burn brilliantly, as represented in the cut.

The end of a spiral iron wire, or of a watch-spring, on being heated red-hot and plunged into an atmosphere of oxygen gas, instantaneously begins to glow more brightly with intense development of the phenomena of heat and light, and then to burn with dazzlingly brilliant scintillations.

These scintillations are constituted of globules of a new grouping of atoms of oxygen and iron, which become so intensely electro-polarized by their contact with each other, as to react on the water contained in the bottom of the vessel, converting it into steam. They appear to leap from its surface as fast as they fall therein.

The sides of the glass vessel, against which these globules are projected, become so intensely affected by the sudden electro-polarization, antagonistical to that which induces their cohesion as solid glass, that they become fused; and, it has been stated, the globules have been known to pass through the glass, producing a perforation without fracture.

The partial combustion of iron, to increase the intensity of its own state of ignition, has been employed with admirable sagacity by blacksmiths in pointing horseshoe nails. In driving these nails into the horny hoof of a horse, the fibrous texture of the iron is liable to yield, and become split, thereby injuring the hoof of the animal. To produce and sustain a perfect *welding heat* in the point of the nail, whilst undergoing the process of being pointed, a stream of atoms of oxygen of the air is forced by bellows into contact therewith. An increased glow of heat is immediately induced, and the state of incandescence becomes augmented to so intense a degree, that the same kind of scintillations take place therefrom, as exhibited in the preceding figure.

By thus directing a blast of air against a bar of iron in a forge fire, the bar may be speedily burnt like a piece of wood. And various kinds of metals subjected to the excitation of heat in furnaces, become similarly reduced to their natural static conditions of groupings of oxides, to the loss of the manufacturers of metals.

Thus all kinds of inorganic and organic formations, which are not actually reduced to their final natural electro-static conditions, are capable of propagating electro-dynamic action to the nerves of intelligent beings, recognizable by them in the modified form of heat and light, whenever the Inorganic reaction induces a change of their relative groupings. This change, at every stage of the progress of their recoil, developes the electro-dynamic action, which is termed combustion.

To illustrate the preceding theory, two instances may be selected, in which inorganic groupings of atoms exhibit all the characteristic properties of fuel, viz., sulphur and pure hydrogen gas.

Sulphur is found naturally existing on the surface of the earth, in certain localities, in pure masses of this yellow material. It is commonly selected as the most readily combustible of all known groupings of elementary matter, and is familiarly available for kindling matches to light fires.

Although sulphur may be found naturally existing in pure masses in the open air, yet this fact does not demonstrate that this state of grouping of the atoms of sulphur is its true final natural electro-static condition. On the contrary, from the exceedingly rare occurrence of pure sulphur on the surface of the earth, and from the fact that it is usually found only in localities where the intense action of volcanoes has disturbed the natural static condition of all surrounding bodies, we have ample evidence that pure sulphur is really in a constrained static condition of grouping of atoms. This conclusion is corroborated by the abundant occurrence of sulphur profusely exsiting every where on the earth's surface in the form of "sulphates" and "sulphites," such as those constituting plaster of Paris, sulphate of zinc, of iron, copper, lead, and numerous other compounds. Science teaches us that atoms of sulphur united with these various substances, are in natural static conditions of groupings, and that these incombustible groupings of atoms *are the true natural static conditions of the groupings of sulphur.* Hence we are led to conclude that the natural masses of pure sulphur, found on the surface of the earth, really exist in the same kind of constrained static conditions of groupings of atoms, as the organic and inorganic formations of fuel, food, vapor of water or steam, of iron, zinc, and other smelted metals employed in the galvanic battery.

The Inorganic reaction, developed during the recoil of atoms of sulphur to their natural static conditions of groupings, admits of being traced through successive stages, precisely as in the fermenting processes, which have just been recapitulated. The atoms of sulphur, on becoming grouped with atoms of oxygen, are reduced first to the stage of sulphurous acid gas, which, on being absorbed by water, constitutes sulphuric acid. Thus, this acid, which is one of the most powerful agents in the laboratory of the chemist, really represents half-burnt sulphur, as pyroligneous acid represents half-burnt wood. It has a strong tendency to become further reduced by Inorganic reaction, whenever brought into contact with atoms of various kinds of substances. When this acid and pure zinc are brought into contact in the battery cell, there is developed a double energy of recoil both in the atoms of the acid and of the zinc.

In the case of the reduction of sulphur, by volcanic action, from its natural static condition of union with other kinds of elementary matter, to the pure state of a mass of this bright yellow substance, there may appear to be an exception to the general law of excitation from the originating source of electrodynamic action—the sun. The system we have thus far sustained would fail, were there a single exception to its universal truthfulness. For this special reason the source of *Ignition*, not of Actual Combustion in volcanoes, requires here a passing notice.

Source of the Ignition of Volcanoes.

The propagation of the electro-dynamic action along the connecting wires forming the circuits of galvanic currents has been noticed in frequent instances, in the preceding discussion, as inducing a state of electro-polarization, adequate to *igniting*, or rendering red-hot, and even to melting, refractory substances. The continuous circuit of a systematic propagation of electro-dynamic action has been shown to take place from east to west about the earth's surface; and in treating of Thermo-electricity, page 339, it has also been shown, that wherever the phenomenon of Heat occurs, there must be a previous, or simultaneous excitation of electricity, the cause of the excitation of the phenomena both of Heat and Electricity being identical, and alike resolvable into the propagation of mechanical action through the medium of electric matter.

The propagation of electro-dynamic action by terrestrial currents, about the circumference of the earth, and the consequent electro-polarization of the atoms of the interior of the mass from this cause of inductive-excitation, has been previously referred to. In treating of Electro-polarization, page 365, the law has been established, that in proportion as the polarization of the exterior of a mass becomes more intense, the molecular polarization of the component atoms becomes less intense, until the former overcomes the latter, as in the phenomenon of Latent heat, and Sensible heat. The former represents the molecular action, as developed internally, and the latter externally to the mass, as denoted by the arrow-heads in the figure, at page 465; where the antagonistical molecular forces counteract the electro-polarization, producing the phenomenon of cohesion, whilst it increases that producing magnetic action.

The excited counteracting electro-polarizations of the interior atoms, act and react on each other within the interior of magnetically-excited masses to neutralize each other, consequently their relative fixations in crystalline forms is counteracted, and the groupings reduced to fluid spherical formations, when the external electro-polarization is paramount in intensity to the internal, or molecular polarization.

The cause of the *internal heat of the earth*, if not ascribable to Electro-dynamic Ignition, will probably remain for ever a mystery.

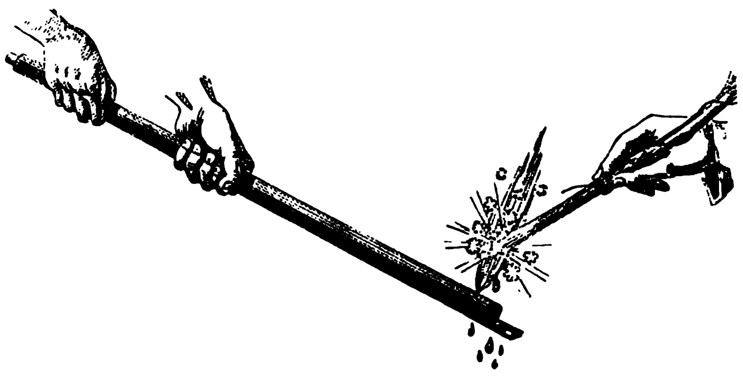
To this cause of ignition the phenomenon of the molten volumes of lava, poured forth from the fluid mass of the interior of the earth, appears to be ascribable.

If the internal heat of the mass of the earth, and consequently of the volcanoes which burst through the external solid shell of its crust, be the effect of electro-polarization, and of vibrations induced by the excitation of electric currents induced to circulate about its surface, by the electro-dynamic action of the sun, as has been premised in treating of this subject, then we are at liberty to trace, also, the constrained static condition of groupings of the atoms of combustible sulphur to the electro-dynamic action of the sun; as the similar constrained static condition of wood and other kinds of vegetable fuel, have been severally traced thereto.

One of the natural static conditions of Sulphur is a grouping with atoms of iron and oxygen, constituting the common sulphuret of iron, found in small cubical crystals resembling gold in color, and often mistaken for an ore of this precious metal. By simply commingling iron filings and the flour of sulphur in a mass moistened with acidulated water, they violently recoil to their natural static conditions, developing the phenomenon of spontaneous combustion.

A bunch of iron wires will burn like a bundle of faggots, if held against a stream of vaporized sulphur, as represented in the

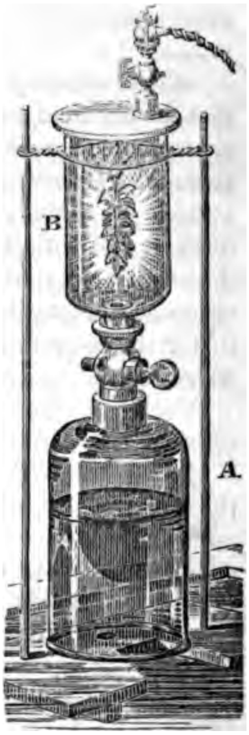
Fig. 131.



'. This experiment admits of being readily performed by ing a small roll of sulphur into a gun-barrel, the lower end ich is heated red hot. If the muzzle is then stopped with ;, an ignited jet of vaporized sulphur will issue from the -hole, and the wire will burn as in the experiment repre- d in figure 130, where a spiral wire is immersed in oxygen

nother common natural static condition of the grouping of ur is with atoms of zinc, constituting an ore of this metal; ı has been particularly referred to in treating of galvanic ex- on. The pure zinc and sulphur being both in constrained o-polarized conditions, it is of course only necessary to their atoms into contact with each , as shown in the preceding experi- with the jet from the gun-barrel, to e a change of groupings, and a conse- ; development of powerful electro-dy- : action.

Fig. 132.



he pure metallic zinc, like the pure of sulphur, constitutes a *combustible ınce*, and consequently they both alike rve the purpose of being burnt as fuel ropagating electro-dynamic impulses, e modified form of Heat, Light, and anical action. When inclosed in pure en gas, and kindled, the zinc will burn pidly and vividly, as the sulphur; ex- ing the identical phenomenon of com- on.

hin leaves of zinc will also burn bril- y in other gases. The apparatus com- y used for exhibiting the experiment ie combustion of various metals in , is represented in the wood-cut, where notes a glass vessel with a cover; to h is appended the metallic leaves to be rimented upon. Communicating with vessel is another vessel, A, from which the gases are pro- d. The upper glass vessel being exhausted of air, by means of an air-pump, on turning the stop-cock the gases rush from the lower into the upper chamber.

Chlorine gas thus brought into contact with thin leaves of zinc, becomes electro-dynamically united therewith, developing splendid brilliancy of light;—that is, an intense propagation of the electro-dynamic action to the electroscopic nerves of the eye.

In the processes of Fermentation and Putrefaction, which have been described, the recoil of the atoms, from constrained to natural static conditions, is slow in comparison with the preceding results. The difference of *time* necessarily condenses the action, and renders it correspondingly more intense.

Precisely similar results also occur when the atoms of sheets of zinc are allowed to recoil slowly to their groupings with atoms of oxygen, whilst immersed in water or in acids. During the prolonged and less intense recoil of the zinc plates, immersed in liquids of a battery cell, it is not to be theoretically anticipated that the electro-dynamic action will be propagated to act on the electroscopic nerves of the eye. This *slow* combustion will not therefore be perceptible. Nevertheless, it may be rendered perceptible by means of connecting the organ of the eye by a conducting wire with the circuit of the recoiling plates of zinc. But if the metal potassium be thrown in water, the recoil from its extremely constrained static condition is so rapid and intense, that it is powerfully propagated through water and air to the nerves of the eyes of sentient beings.

The combustion of pure hydrogen gas as Fuel, will next be considered as furnishing instructive information.

During the union of the atoms of oxygen of water with those of the zinc, the atoms of hydrogen become simultaneously reduced from their natural static condition of grouping with the atoms of oxygen, to the constrained static condition of pure *hydrogen gas*. It then represents fuel, food, and the pure groupings of atoms of the zinc and sulphur. Like them, it in turn becomes polarized by the Inorganic reaction, and serves to propagate mechanical impulse in the modified form of combustion.

From the familiar fact of the conversion of one of the elements of water into *fuel*, by reducing it to the constrained static condition of pure hydrogen gas, innumerable attempts have been made to render this gas economically available for the practical purposes of lighting and heating habitations, and for propagating mechanical impulses in the specific form of exciting steam power. But as action and reaction are in all cases equal, the preceding facts demonstrate clearly, that the electro-dynamic action brought to bear upon a quantity of water to reduce one of its elements to the constrained static condition of pure hydrogen, must at any rate be equal to the electro-dynamic reaction which will be developed during its recoil to its natural static condition. Allowing no waste of electro-dynamic action during the process of decomposing the water, in point of economy it must be preferable rather to employ the electro-dynamic power directly to produce the desirable results of illumination and of heat, than to employ indirectly the same extent of electro-dynamic power propagated through the medium of the recoiling inorganic reaction developed by the combustion of this gas.

As the grouping of atoms of pure chlorine, like that of pure hydrogen, represents an exceedingly constrained and delicately counterbalanced static condition, it requires but a slight electro-dynamic action in the exciting form of a gleam of sunshine to produce the instantaneous union of its atoms with those of hydrogen, as has been illustrated in treating of the electro-dynamic action of "light."

But the most remarkable property of pure hydrogen gas is its ready spontaneous combustion, simply by contact upon the points of fine platinum wires, or upon a mass of spongy platinum. The movement of the jet of gas first excites the metal, which reacts by electro-polarizing the atoms of hydrogen, whereby it becomes ignited. A nearly similar polarization of the atoms of hydrogen contained in alcohol has just been related, where this liquid becomes spontaneously converted into the half-burnt substance of vinegar by means of a coil of platinum wire wound around the wick of a spirit lamp.

The remarkable fact of the kindling of a jet of hydrogen gas into a blaze by impinging on platinum, was first discovered by Dobereiner, in the year 1824. An ingeniously arranged apparatus was invented for kindling tapers and fires by means of this process, before the facilities of *friction matches* were introduced into common use.

It has been previously noticed that the electro-dynamic excitation producible by the sudden compression of air inclosed in a tight tube beneath a piston will kindle tinder; and if a mixture of two parts of oxygen and one of hydrogen be substituted in place of air, a powerful detonation will instantaneously ensue under similar treatment. By this excitation the polarity of the two kinds of atoms appears to be so far affected, as to admit of their being brought within the sphere of their mutual attraction, so as to resume their natural static condition.

By the combustion of hydrogen in connection with pure oxygen, Dr. Hare has eminently taken the lead in developing an intense degree of heat, never before equalled. He contrived an apparatus for combining together jets of the two gases, which is well known in chemical laboratories by the name of "Hare's compound oxy-hydrogen blow-pipe."

The spontaneous combustion of phosphorus is too familiarly known to require a description here. Like hydrogen, this substance is always found in union with groupings of other kinds of atoms. Chemical skill is similarly requisite to detach them from their union and to obtain them pure. They are collected and grouped by organic action into the composition of animal bones, constituting the phosphate of lime. The lime is separated by sulphuric acid; and the residuum is mixed with charcoal and subjected to a red heat in a retort. The phosphorus is distilled in drops or tears from the beak of the retort immersed in water.

A violent electro-dynamic process is resorted to for the purpose of reducing phosphorus to a pure state, as in the case of producing pure hydrogen; but its recoil to its natural static condition is in some respects less intense. During its union with the atoms of oxygen it developes the phenomenon of a pale light, with scarcely perceptible degrees of heat.

There is also a slow combustion of various kinds of vegetable and animal bodies, which developes an electro-dynamic action recognizable by the nerves of vision, as that of *light*. This slow combustion takes place in moist, instead of in very dry bodies. The supply of oxygen is furnished by *moist* air, a portion of the water probably yielding its oxygen to the decomposing atoms of the hydrogen of the organic formation with which the atoms of oxygen become united, thus reproducing water as well as carbonic acid gas.

Pieces of rotting wood, decaying fish, &c., are frequently to be seen undergoing this species of slow combustion, shining in the dark with a pale phosphorescent light.

Plants of the fungus species also spring forth from the decomposing wood, each cherishing its peculiar tribe of animalculæ, and rapidly becoming decomposed, sometimes with such intense electro-dynamic action as to affect the nerves of the eye. Mr. Gardner states, that during his travels in Brazil he saw some plants of a species of fungus, 1 to 2½ inches diameter, which gave out a bright phosphorescent light; and by combining a few of them together, the light was sufficient to read by in a dark room.

That there is an electro-dynamic action developing the phenomenon of heat as well as light, from the presence of this phosphorescent or slowly-burning organic matter, has been demonstrated by means of the excitation of a thermo-electric apparatus, page 351.

To facilitate this process a temperature of 60° or 70° of Fahrenheit is requisite. In certain conditions of exposure to a warm steamy atmosphere, large beams and timbers of wood become speedily reduced to a soft punky state, devoid of all cohesive strength, as is too often found to occur in the DRY-ROT of the timbers of ships, when included between the external and internal planking, and shut out from the free circulation of the air. The joists beneath floors laid on the ground in the basement of buildings are peculiarly liable to this species of slow combustion.

Very elaborate experiments have been made of saturating wood with chemical compounds to obviate the vast deterioration of property which ensues from this cause.

Various nostrums have been prescribed for the purpose of arresting this slow process of combustion in timber, by artificially producing new groupings of the component atoms of this material. Corrosive sublimate of mercury most effectually accomplishes this result by combining with the albuminous matter, which is most prone to fermentation. This powerful chemical substance, in solution with common salt, has been recommended by Kyan. Another plan is that of Payne, which prescribes the saturation of the pores of the wood with chloride of lime, followed by a forcible injection of the sulphate of iron, whereby there is deposited in the body of the timber a strong insoluble gypsum. Pyroligneous acid and coal tar have in turn had their advocates, as being specifics against the dry-rot and decay of timber.

The removal of the cause, wherever practicable, is more certain than any remedies. This is best accomplished by ventilation, to carry off the superfluous moisture. This may be in nearly all cases effected beneath floors laid near the ground. As an elevated temperature induces this fermentation, I have had occasion to notice that floors laid immediately above the earth, when moist with cold spring water, have remained sound for nearly a century.

When certain organic formations, such as fibres of cotton or wool, are moistened with substances which readily part with their component atoms of oxygen to these formations, such as water, drying oils, varnish, &c., they speedily begin to undergo this slow combustion, and present the familiar phenomenon of SPONTANEOUS COMBUSTION; with the practical results of which Insurance Companies frequently gain scientific experience by costly lessons.

Various groupings of atoms reduced artificially to constrained static conditions by chemical processes, exhibit the phenomenon of spontaneous combustion, when brought into contact together, as when sulphuric acid is poured into spirits of turpentine, or upon baryta and magnesia.

The extinguishment of fire by water, is a case of the speedy arrest of the recoil of organic and inorganic formations to their natural static conditions. The philosophy of this process does not appear to have hitherto attracted notice. It is worthy of consideration, as illustrative of the subject which occupies our present attention.

During the process of ordinary combustion, the atoms of the recoiling fuel become grouped with atoms of oxygen of the atmosphere. To overcome the electro-polarization of the atoms of the fuel, a temperature of 700° to 1000° of Fahrenheit's scale is necessary. When water is brought into contact with a burning body, this extreme intensity of polarization is propagated to the atoms of the water, which become electro-polarized and reduced to the constrained static condition of steam, at a temperature of only 212° of the same scale. The electro-dynamic action is propagated from the burning mass faster than it is excited, and thus the temperature becomes immediately reduced below the point necessary to sustain the combustion.

In some cases the electro-polarization of the recoiling fuel may be so intense as to overpower the natural electro-polarization of the component atoms of the water. Then the resistance to the recoil of the burning body occasioned by the presence of water, becomes reduced simply to the difference of electro-dynamic action requisite to decompose water, and atmospheric air. Potassium, whilst immersed in water, exhibits an instance of this kind, as it continues to burn brilliantly, even when immersed in water.

In tracing out to their originating cause, the preceding phenomena of COMBUSTION, FERMENTATION, PUTREFACTION, AND EXPLOSION, accompanied by the simultaneous development of the phenomena of HEAT, LIGHT, ELECTRICITY, and of NATURAL MOTIVE POWER, it has appeared manifest that they are all to be considered as results of the propagation of mechanical impulses through the medium of electric matter.

PROPAGATION OF MECHANICAL ACTION BETWEEN GROUPINGS OF ATOMS, THROUGH THE MEDIUM OF ELECTRIC MATTER IN THE FORM OF

HEAT, OR CALORIC.

" A mechanical action is the equivalent of an increase of temperature."
Holtzman.

That the sun is the great source both of Heat and Light to terrestrial matter, is a fact too obvious to require detailed proofs. But the fact of the continuous propagation of the electro-dynamic excitation of the sun between groupings of atoms in the specific form of Heat, is not so palpable to common observation.

As the propagation of mechanical impulses in this modified form, constitutes the most important physical power available by man, this subject is to be regarded with special interest in tracing out the Sources of Natural Motive Power.

Before proceeding to the investigation of the essential nature of Heat, the difficulties to be encountered may be profitably anticipated by taking a brief preliminary view of the present popular doctrines promulgated in the most recent standard works on chemistry.

Chemists have considered that the term *Heat* has two distinct meanings; one of which has reference to effects produced, as for instance, the *sensation* experienced in touching a hot body; and the other has reference to the *cause* of these effects. The cause of the effects of Heat has been termed CALORIC, from the Latin word Calor, signifying Heat. But both the cause, and effects producible thereby, continue to be denoted popularly by the same common term, "Heat."

Dr. Turner, in his "Elements of Chemistry," after discarding the phlogistic theory of heat, introduced by Stahl, and also that advanced by Lavoisier, remarks, "that it is easier to perceive the fallacies of one doctrine, than to substitute another which shall be faultless; and it appears to me that chemists must, for the present, be satisfied with the simple statement, that energetic chemical action does itself give rise to an increase of temperature."

He admits that "there are, indeed, strong grounds for believing that electrical action is an essential part of every chemical change, and it is probable that the heat developed during chemical changes may be due to electrical action; but this part of the science is yet too imperfect for indicating the precise mode by which the effect is produced."

Notwithstanding this allusion to electrical action, as a cause of the heat developed during chemical changes, yet the admission appears to be lost sight of in his subsequent explanation of the mechanical forces of "repulsion," developed by the excitation of heat; for, he continues, "it is a general opinion among philosophers, supported by very strong facts, that this repulsion is owing to the agency of *heat*, which is somehow attached to the elementary molecules of matter, causing them to repel one another. Natural substances are therefore subject to the action of two contrary and *antagonizing forces*, one tending to separate their particles, the other to bring them into closer proximity." And Dr. Bache, the American editor of this treatise on chemistry, adds, in an explanatory note, "that the force which tends to bring the elementary molecules into closer proximity, is derived from an *innate property* of ponderable matter; while the force which tends to separate them is dependent on the operation of a distinct principle, Caloric, the particles of which, being self-repellent, force the ponderable particles asunder."

"In order to explain why the caloric remains attached to the ponderable molecules, it is necessary to suppose that its particles, though self-repellent, have an attraction for ponderable matter."

In detailing the facts of the action of heated bodies on the sensitive nerves of the eye, Dr. Turner further states, that "when heat is accumulated to a certain extent in bodies, they are said to *shine* or become *incandescent.* On this important property depends all our methods of artificial *illumination.*" Thus the functions of the "imponderable agents," heat and light, are confusingly blended together.

Müller affirms, in his recently published treatise on Physics, that "the forces which are continuously acting between the adjacent atoms or molecules of bodies, are termed *molecular forces.* The force which holds together the particles of a solid body, is termed the *force of cohesion*, which we assume to be called forth by a mutual attraction of atoms. Now if atoms mutually attract each other, and heat be deemed material, it is not easy to understand how this latter kind of atoms can mutually repel each other; therefore, to explain this repulsion, as observable in gases, we assume that there is another and an opposite force, which we term the *force of expansion.*"

At the commencement of the first chapter of Graham's Treatise on Chemistry, the author remarks, "our knowledge of heat is limited to the different *effects* which it produces upon bodies, and the mode of its transmission; and these subjects may be considered without reference to any theory of the nature of this agent." These effects he considers under five different heads, viz., *expansion*, *specific heat*, *communication of heat by conduction* and *radiation*, *liquefaction*, and *vaporization.*

"It is convenient to adopt a material theory of heat," he continues, "in considering its accumulation in bodies, and in expressing relative quantities of heat, and the relative capacities of bodies for heat; for heat, unlike light, is never extinguished when it falls upon a body, but is either reflected, and may be further traced, or is absorbed and accumulated in the body, and may be again derived from it without loss," &c. "When the calorific rays of the sun pass through glass, and strike a black wall, they are absorbed, and appear immediately afterwards radiating from the heated wall."

In a recent publication on the subject of heat, or caloric, by Mr. Metcalfe, the following explanation appears to be the summary conclusion to which the author finally arrives.

"By the affinity of ponderable matter for caloric, its atoms are approximated and held together; by the elastic or self-repelling property of caloric, it separates the atoms from each other, as in gasefaction, explosion, and all decompositions." He continues, "this doctrine throws a clear and full light on all the powers, motions, combinations and decompositions of the elements by which we are surrounded and sustained; and when perfectly unfolded in all its relations, will be found to furnish a simple and rational interpretation of the book of nature." Again, at page 176, he observes, "by the attraction of caloric for ponderable matter, it unites and holds together all things; by its self-repulsive agency it separates and expands all things."

These vague sentences are the summary result of the information contained in a treatise on heat, which occupies the pages of two considerable octavo volumes. He uses the terms, "attraction of caloric," and of "self-repulsive agency," to designate both the causes and effects of the action of heat; and we glean from his volumes, therefore, little more than a statement of mechanical *effects* produced.

The preceding brief extracts will be sufficient to show the present unsettled state of the science of Heat. These imperfect views of this mechanical agency may serve as convenient fictions for illustrating and classifying the facts of the grouping of atoms into the combinations, of which it is the peculiar province of the science of chemistry to give a descriptive account. But these vague assumptions are not admissible in the science of Mechanics, in answer to inquiries into the cause of the natural motive power, which produces the states of rest and motion of matter.

The fact of heating fine wires red-hot by the propagation of electric action through them, and of the consequent development of every characteristic phenomenon of heat, has been repeatedly adverted to in the preceding pages. In treating of the subject of Heat, a few details will be added of the practical results effected by the application of this excitation.

It appears that a pair of zinc and copper plates, only one or two inches square, will render red-hot one inch in length of platinum wire, of the diameter of $\frac{1}{100}$th part of an inch. As the sizes of the battery plates are increased, their heating power is augmented, as has been detailed (page 330, figure 78) in describing Hare's calorimeter.

Dr. Hare states that in proportion as the pair of zinc and copper plates are enlarged, a larger wire may be rendered incandescent; and by multiplying the number of the series of plates of the same size, a greater length of wire of the same size or diameter may be rendered incandescent.

A piece of platinum wire, $5\frac{1}{2}$ feet long, and $\frac{1}{10}$th of an inch in diameter, was rendered red-hot by Mr. Children's large galvanic battery.

In heating wire to a red heat by electrical action, it is found that the middle portion of the wire becomes first ignited, and the incandescence gradually becomes extended to the two ends of the wire.

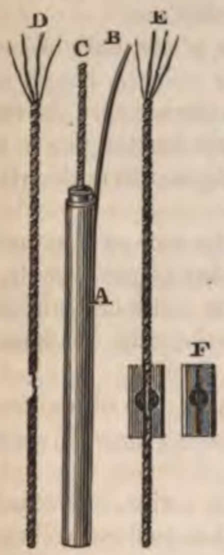
The discharge of a powerful Leyden battery not only ignites but even fuses into the globules a considerable extent of conducting wires.

The excitation of heat by galvanic batteries has of late years been frequently employed for igniting gunpowder in mines and stone quarries, and even for producing submarine explosions.

It is only necessary to solder a short piece of *fine* platinum wire constituting a portion of the *coarser* conducting wire of an extended galvanic circuit, to render the fine wire red-hot immediately in closing the contact with the battery pole. If this piece of fine wire be arranged in contact with gunpowder it becomes ignited.

A number of these fine wires may be arranged in contact with several magazines of gunpowder to produce simultaneous explosions. By thus firing at the same instant several blasts in rocks, long seams and large masses may be split off and detached therefrom. For firing charges of gunpowder in drill-holes in rocks, Dr. Hare has contrived the arrangement represented in the wood-cut. A, denotes the tin cylinder filled with gunpowder; C, denotes a cord of twisted wire, of two or three strands, as represented at D. One of them is of the finest size, and the others of about No. 24. From a portion of this twisted wire are cut out all the coarse wires, leaving only the fine one. This corded wire is inserted through a cork in the top of the tube, and is extended to the bottom of it, to which it is soldered. To the side of the case is soldered a copper wire, forming the returning circuit, B. To prevent the breakage of the slender wire, it is drawn into a groove or saw-kerf made in a piece of hard wood, E, in the cavity of which some gunpowder is compactly placed. The explosion may be rendered more immediate by substituting fulminating powders, composed of the nitrates of mercury, or of silver, or the combustible preparation used for friction matches.

Fig. 133.



By inspecting the preceding figure, it will be perceived that the battery circuit is established by propagating the electro-dynamic action down through the usual dry sand or compacted matter, confining the charge in drilled rocks, and through the cork to the powder contained in the case beneath. Passing through the fine wire to the bottom of the case, the returning circuit is propagated by the conducting wire B, back to the opposite battery pole.

Remarkable instances of the employment of the excitation of heat by electricity for producing important explosions of gunpowder have been recorded occasionally in public journals. Among the most surprising is the submarine explosion whereby the wreck of the Royal George was blown to pieces in the harbor of Portsmouth, beneath a depth of nearly one hundred feet of water. In preparing the way for a railroad along the face of the cliffs of Dover, nearly a million of tons of earth were displaced by several explosions of gunpowder fired instantaneously by wires ignited by a galvanic battery stationed at a distance of 1000 feet therefrom. Three distinct mines, containing each about 6000 pounds of gunpowder, were simultaneously fired in this sublime experimental test of the powers of electric action in the modified form of Heat, and the labor of twelve months was accomplished in a few minutes.

The following graphic description, from the London Times, gives an interesting account of this grand achievement of the art of man. "A low, faint, indistinct, indescribable, moaning subterraneous rumble was heard, and immediately afterwards the bottom of the cliff began to belly out, and then, almost instantaneously, about 500 feet in breadth began gradually, but rapidly, to sink. There was no roaring explosion, no bursting out of fire, no violent crashing and splitting of rocks, and comparatively speaking, very little smoke. The rock seemed as if it had exchanged its solid for a fluid nature; for it glided like a stream into the sea," &c.

A successful experiment has been made of the employment of a current of galvanic electricity to ignite fine wire in caissons containing gunpowder submerged at the entrance of New-York harbor, for the purpose of ascertaining the practicability of rendering available a new and formidable system of harbor-defences against invasions of hostile fleets. "At the instant of the signal given, the hulk, stationed over this submarine mine, was seen to rise upwards in shattered fragments."

That the excitation of the phenomenon of heat is due to intense development of electrical excitation, if it be not indeed truly an electrical phenomenon, appears to admit of an admirable illustration by the following experiments reported by Mr. Snow Harris.

Comparative table of the development of HEAT *in various kinds of metals used as conducting wires.*

Metals.	Comparative ratio of Heat evolved.	Comparative resistance to conduction of Electricity.	Comparative resistance to the conduction of Heat.
Silver,	6	1	97
Copper,	6	1	89
Gold,	9	1½	1·00
Zinc,	18	3	36
Platinum,	30	5	38
Iron,	30	5	37
Tin,	36	6	30
Lead,	72	12	18

By carefully comparing the degree of heat evolved with the comparative resistance to the conduction of electricity, it will be found that precisely in the ratio that the conducting bodies obstruct the propagation of the electro-dynamic action through them, they exhibit a corresponding equivalent propagation of the same electro-dynamic action in another modified form popularly recognized as that of "Heat." The metal silver being taken as the standard of comparison, or the unit, and lead being found to absorb 12 fold more of the electro-dynamic action, it actually exhibits the same relative increase of the electro-dynamic action in the form of *heat*, being 12 fold of that of the silver, as denoted by the ratio of 72 to 6.

Thus the continuous propagation of any given extent of electro-dynamic impulses is accounted for very exactly either in the modified form of the action of electricity transmitted to act at a distance, or in that of physical action on the wire in the modified form of Heat. Thus also is demonstrated the ready convertibility of the one class of phenomena into those of the other, if not their absolute identity.

The continuous propagation of the same electro-dynamic action through the conducting bodies, which receive a portion of the impulses in the form of *heat*, as above specified, admits of being further extended beyond the end of such conducting body in the modified form of *light*, or *lucifer action*, as occurs in an electric spark, or current, between two charcoal points, as will be presently more particularly detailed.

In investigating the nature and properties of heat, it becomes necessary first to examine the standard texts by which these properties are to be judged.

Expansion of Bodies, or the Occupancy of a Greater Extent of Space by Groupings of Atoms, considered as a Test of the Agency of "Heat."

The expansion or separation of the atoms of mercury in the bulb of a thermometer, is resorted to by mankind as the most convenient test of the action of "Heat;" in like manner as the separation of a pair of diverging pith balls is similarly resorted to as the surest test of the action of electricity. In both cases, therefore, a mechanical action constitutes the test resorted to for determining the phenomena of heat and of electrity.

That the expansion of bodies by heat is not produced by the mere absorption of a material fluid, as a sponge is swelled by the absorption of fluids, is manifest from the extraordinary irregularity of the expansion of bodies, whilst their component atoms are subjected to a gradually augmented temperature. A quantity of water is caused to occupy 1700 fold more space by increasing its temperature from 212° to 213° on Fahrenheit's scale of the expansion of the mercury in the tube of the thermometer. And then, again, the very mercury itself at a certain degree of the increase of its temperature becomes similarly expanded into vapor, like the steam of water. Whilst on the other hand, on cooling water and crystallizable melted metals, it is experimentally found that at a certain stage of reduced temperature they all suddenly become expanded with intense violence, as has been described in the bursting of cannon by the freezing of water.

These facts conclusively show, that although to a certain extent the regular expansion of bodies becomes a sufficiently accurate test of their steadily augmented temperature, yet this principle of expansion is truthful only to a limited range in all groupings of elementary atoms. The dynamic action which becomes simultaneously developed with every change of the groupings of atoms from one electro-static condition to another, interferes with the regular expansion of bodies, producing the most extraordinary discrepancies to any uniform law of expansion by heat. Thermometers are, therefore, strictly reliable philosophical tests of the cause of the phenomenon of heat only to limited degrees of changes of temperature.

Besides, it appears from a recent communication of Plucker to Arago, that air in the bulb of an air thermometer is caused to become expanded in volume by being exposed to the electro-polarization induced by the two poles of a powerful electro-magnet.

To explain the phenomenon of the expansion of bodies by heat, it will be necessary to recur to the principles established in treating of the grouping of atoms into visible magnitudes. All such groupings being mechanical effects produced by continuous mechanical impulses holding them together in masses (page 71), it follows, as a consequence, that all our knowledge of the properties of matter, including that of developing the phenomenon of heat, is traceable to the reciprocal mechanical actions and reactions between the atoms of masses constituting *molecular action*. The law established by Dulong and Petit (page 76), showing that there exists a relationship between the weights of each kind of ultimate atom and its specific heat, demonstrates conclusively this fact. The *weight* of each atom actually represents the mechanical action developed between it and the mass of matter of the earth, and the *specific heat* of each atom represents the development of a corresponding extent of mechanical action between the groupings of approximated atoms. It having been found that each kind of "simple atoms has the same capacity for heat," the conclusion has hence been deduced that "the specific heat of a body thus affords the means of fixing its atomic weight."

The theory of *latent* heat, advanced by Dr. Black, admits of an admirably simple illustration, by the application of the principle of the continuous propagation of mechanical action between groupings of atoms through the medium of electric matter by successive static and dynamic conditions of their electro-polarizations (page 359), as demonstrated by the constancy of the united sums of the latent and sensible heat of steam.

The discussion of this subject has been mainly anticipated in the chapter on THERMO-ELECTRICITY. By means of the instrument represented by figure 88, page 354, it has been shown that changes of temperature from heat to cold may at pleasure be produced, simply by changing the direction of electric currents.

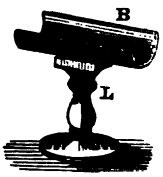
The excitation of Heat, Light, and Electricity, has been traced to the propagation of mechanical action in variously modified forms, through the medium of electric matter, as will appear on recurring to page 344 and 352. Little more remains than to classify the facts and principles there detailed.

Considering that the action of impulses of mechanical force constitutes the properties of matter to a certain extent, and that the phenomenon of heat is the result of this action among the constituent atoms of bodies, we may consider the loss or gain, the development or non-development of Heat, simply as changes of intensity of mechanical action; and we have reason to calculate, on this principle, that although no ponderable constituent atoms of a body may be lost or gained, yet changes of intensity of electro-dynamic forces may produce such a difference in the relative states of union of all kinds of atoms, as to render manifest entirely new and different characteristic properties in the bodies composed of them.

The following experiment serves to show that the phenomenon of the expansion of bodies, considered as a test of the increase of their heat, may be ascribed to the vibrations of their component atoms actually producible by changes of their temperature.

Mr. Trevelyan states,* that peculiar vibrations are found to take place between metallic masses of different temperatures; and a rocking motion may be thus imparted to a large piece of brass, if suitably formed for this purpose. Let B represent a *heated* curved bar of brass, placed upon the cold flat surface of a supporter or stand of lead, L. The thermo-electric action, which takes place at the point of their reciprocal contact, produces a *vibration* and *rocking* motion of the brass bar, thus rendering direct evidence of the action of impulses of mechanical force from this source of exciting power.

Fig. 134.



The intense vibratory motion even produces a sound resembling a musical note of a glass harmonicon.

The most intense vibratory action is producible, according to

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* Phil. Magazine, 3d series, vol. III, page 321.

Professor Forbes' experiments, between the best and worst conductors of heat, the latter being used as the cold body.

Theory would lead us to infer, that if the phenomenon of "heat" be an effect produced of the rapid vibration of electric matter existing in connection with groupings of grosser elementary atoms, that the rapid magnetization, and demagnetization of soft iron bars, or of the *keepers* of magnets, should produce such a disturbance of their electro-static conditions as to develope dynamic action corresponding with that of "*heat.*" This fact appears actually to have been verified by the experiments of Mr. Grove. He succeeded in producing, in a cylindrical cast-iron keeper, when rapidly magnetized and demagnetized, a rise of temperature of several degrees beyond that which occurred in the electro-magnet, and which therefore could not have been due to the radiation of heat from it. Subsequently, "distinct thermal effects were detected in a bar of soft iron placed opposite to a rotating permanent steel magnet."

Considering, then, the rapid molecular vibrations of atoms to represent the mechanical action which Holtzman affirms to be "the equivalent of an increase of temperature," we are afforded a direct clue to the *gradual scale of expansion of bodies by heat.* Neither atoms nor masses can be put into vibratory motion without occupying more space to admit of this vibration; for a body cannot vibrate without changing its place in space; and to allow of this it must necessarily occupy more room, which is equivalent to an increase of volume.

But the sudden expansion of all bodies capable of being reduced by the action of heat from solid to liquid states, and also to aeriform states, shows a speedy limit to this range of expansion, as exhibited when the heat applied to the mercury in the ball of the thermometer exceeds 660° degrees (Fahr.). The atoms of mercury, when reduced to this extreme degree of vibration, become so far removed asunder by the electro-dynamic impulses, as to pass beyond the sphere of their natural static conditions of electro-polarization. At the instant this effect is produced, a new order of electro-polarization becomes established among the atoms. They at once occupy many fold more space, precisely as when water is converted into steam by an increase of temperature of 1° over 212°.

Here, then, is brought into play another cause of expansion entirely different from that of *Vibration*, as above stated. Microscopic observations have not yet disclosed what the exact order of arrangement of the atoms may be in this new electro-polarization of them. Reasonings from analogy, lead us to infer probable changes from polar to equatorial arrangements of the atoms (figure 23, page 225), corresponding with the dia-magnetic action (page 501), the latter predominating over the former.

From the fact that the grouping of atoms of water occupies 1700 fold more space by the increase of only one degree of temperature, as denoted by the scale of the thermometer, we cannot conceive that this extraordinary expansion in volume can take place without an arrangement of the polarization of the atoms corresponding with those artificially producible by means of establishing electro-dynamic circuits or circles. These are represented by the white volume of smoke formed into Electro-dynamic Rings (fig. 121, page 477), which are combined into vesicular or globular forms, like soap bubbles artificially produced (page 478).

To reduce the grouping of atoms of water to this extreme electro-polarized condition, must require a correspondingly extreme propagation of electro-dynamic action, accompanied by a simultaneous reaction necessarily to be overcome, and to be re-developed on the recoil of the atoms of steam from their constrained static condition to their natural static condition of water.

This reaction appears to constitute the phenomenon of *latent heat*, developed by the *condensation* of steam. And considering latent heat to represent the propagation of mechanical action through the medium of electric matter, the continuous propagation of this mechanical action may be traced in the various specific forms of Electric Sparks (page 38), of Heat, Light, Steam-power, Animal Motive-power (page 42), and of Attraction and Repulsion (page 44). By watching these Protean changes, the mechanical action propagated through the medium of electric matter may be traced continuously, and detected with unfailing certainty.

This is the best account which it is in our power to offer in explanation of the phenomenon of the *expansion of water into* STEAM *by means of* HEAT.

Friction and other processes of Mechanical Action on bodies, considered as a cause of Heat.

Every mechanical movement of bodies near each other, as well as in contact with each other, has been demonstrated to be a cause of electric excitation, and of the consequent propagation of mechanical action in some of the variously modified forms which have just been recapitulated: consequently every cause of the excitation of electricity is a cause of the excitation of Heat.

One of the most obvious and simple experiments demonstrating that the sensations of heat, as tested by the nerves of feeling, originate from mechanical action, is readily made by rubbing any part of the body with the palm of the hand. The movement of the hand, whilst pressed upon the surface of the body, produces the sensation of heat, both in the nerves of the hand, and in those of the parts of the body subjected to friction. By a violent mechanical action or friction of the heel upon a dry carpet, the effect of a burning heat is producible, even to the blistering of the skin.

Dr. Turner affirms, "there appears to be no limit to the production of heat by means of *friction*." This is equivalent to affirming that there appears to be no limit to the transmission of impulses through the medium of electric matter, so long as such impulses are continuously imparted thereto. This result was practically verified by Rumford (page 58). So long as he continued to impart the mechanical action originating either from the solar excitation of water power or steam power for the purpose of boring cannon, he found that the friction of the parts of the boring apparatus continuously transmitted this mechanical action in the form of sensible heat, sufficiently to keep water constantly boiling.

Deeming friction simply a mechanical action, and nothing material in itself, he sagaciously concluded that heat could not be material. Thus nearly did this eminent practical philosopher arrive at a true conception of the nature of heat, as being simply the transmission of mechanical action through the medium of electric matter.

The propagation of mechanical action in the many and varied forms of light, chemical action, and steam, as well as in that of heat, was once simultaneously exhibited to me in an impressive manner during an experimental trial of the effective motive-power of a large Turbine water-wheel of about 80 horse-power.

To produce a resistance of friction corresponding with this powerful mechanical action, two pieces of timber were applied to the two opposite parts of the circumference of a stout iron wheel, which was compressed between them by tightening the screw bolts connecting them. This iron wheel was fixed upon the vertical shaft of the Turbine wheel. The surface of it was smoothly turned to prevent abrasion of the wood. A rope, with a heavy weight attached to one end, was passed over a pulley and attached by the other end to the extremity of the timber, which furnished the advantage of a long lever. The tension thus determined in pounds being multiplied into the velocity, in feet per minute, of the revolving surface of the rim subjected to friction, served as the basis for calculating the motive-power thus developed.

To guard against the anticipated excitation of heat by friction, and the consequent burning of the sides of the timbers compressing the iron rim, a small jet of water was directed to trickle upon each of the compressing surfaces of the beams.

When a full head of water was turned upon the Turbine wheel, there appeared to be a force developed equal to that of about eighty horse-power of Boulton and Watts' standard, which was expended in the action and reaction of the friction between the rubbing and rubbed parts.

So intense was this mechanical action, developed by the process of Friction, that the two small streams of water became speedily converted into steam, which issued forth during the first trial, as if discharged from the stop-cock of a steam-boiler. The wooden beams finally took fire, and amid the cloud of vapor and smoke the lights became extinguished, and the half-suffocated workmen were compelled to retreat, until the rubbing parts could be drenched with a more abundant jet of water.

In contemplating the volume of rushing steam, attended with scintillations of sparks, and smoke from the charred wood, the interesting spectacle impressed upon my mind a striking proof of the remarkably diversified modifications of the propagation of impulses here displayed, originating from the electro-dynamic action of the sun. Commencing with the solar evaporation of the ocean waters, this action was propagated through the various stages of clouds and condensing rain-drops, accumulated in the waters of the mill-stream, to produce an available water-power equal to that of eighty horses. This extent of mechanical action was propagated by friction to reproduce an extent of steamy vapor adequate to operating a tiny model of a steam-engine. There was a simultaneous development of the phenomena of Heat, Light, and Chemical Decomposition of the organic formations of the beams of wood.

No link was here wanting of the chain in the successive propagations of the electro-dynamic action of the sun between atoms and masses of terrestrial matter at insensible distances, and of masses at sensible distances, through the medium of electric matter.

Wherever there is a propagation of electro-dynamic action, there must be an equal and opposite electro-dynamic reaction, in accordance with an often-repeated law of mechanical science. Hence we arrive at the conclusion that the RESISTANCE TO MECHANICAL ACTION *popularly ascribed to* FRICTION, *is an* ELECTRO-DYNAMIC REACTION.

That the mechanical resistance which is found to take place between the surfaces of bodies sliding over each other may be due to electro-dynamic forces, or essentially modified thereby, the following experiment seems to demonstrate.

Let one end of a glass tube be roughened by grinding its surface with emery applied to a piece of sheet lead; whilst the other end of the tube is left with its natural smooth and polished surface. Apply a rubber, suitable for exciting electricity, to the surface of this tube by a longitudinal process of friction, so that each stroke may be made to traverse equal portions of the roughened and polished surfaces, commencing the stroke on the polished part, and terminating it on the roughened part. The established mechanical theory of friction teaches us to anticipate that the greatest obstruction or resistance of friction will occur whilst the rubber is passing over the roughened surface of the glass; and the least obstruction whilst the rubber is gliding over the polished part. But the reverse of this fact is found to be the case; for the polished part of the surface of the glass acquires positive excitation, and the rubber the negative state of excitation, and a consequent attractive and adhesive force ensues between them, which presents the phenomenon of *friction* to a considerable degree; but when the same rubber, in its progress, passes over the roughened surface of the glass, it becomes positively excited, instead of negatively, and the rough glass negatively instead of positively, and hence a repulsion ensues, which actually reduces the resistance of friction, by permitting the rubber to slide more easily over the rough than over the polished surface. The anomalous fact, in practical mechanics, that more intense friction sometimes occurs between exquisitely polished surfaces than between the same surfaces less highly polished, may be therefore similarly due in some degree to electrical agency; and the properties of oil to reduce the friction of the rubbing parts of machines, may be due also to the same agency. The presence of oily matter in the composition of the amalgam applied to rubbers of electrical machines, contributes most essentially to the development of the excitation of similar repellent electric forces. On this same principle of the development, in approximated bodies, of similar electrical conditions of excitation causing the phenomenon of repulsion to ensue, it may be found that the slightest force is sufficient to draw a piece of white silk over the surface of another similar piece of white silk; whilst by substituting one of the same pieces of silk after being dyed black, it will require a force of several pounds to overcome the friction which ensues from the mere change of the electric condition, induced by the change of its color in the process of dyeing. The law of increase of pressure doubtlessly has an influence in this case, combined with electric action.

M. Becquerel, by a course of experiments, has sought to determine the phenomena which took place when two bodies were subjected to the action of a given pressure, and then quickly separated. He found that the excess of electricity acquired by each body was *proportionate to the pressure*, as long as it was not great enough to disorganize the body.

This law is the same as that which actually governs the increase of the mechanical friction of bodies, and also of the heat resulting therefrom; and serves to corroborate the suppossition, that the resistance of friction of smoothly polished metallic surfaces may be essentially due to the dynamic reaction propagated through the medium of electric matter.

THE CONDUCTION OF HEAT has been referred to at page 344, as being analogous to the propagation of electro-dynamic action through different bodies. The action and reaction of currents induced by thermo-electric excitation are more intense, as the abbreviated closed circuits become more restricted to specific parts of non-conducting bodies.

Every disturbance of the temperature of a body is capable of propagating through the medium of conducting wires to remote distances sufficient mechanical action to turn a galvanometer needle on its pivot (page 352), precisely as when the electro-static condition of such body is disturbed. The final action on the needle becomes alike resolvable into mechanical impulses, whether a red-hot iron bar, a cold steel bar magnet, or an electrically excited body be moved toward a body, as a disturbing cause. There appears to be no link wanting in the chain of evidence to establish the complete similarity of the modes of propagating mechanical action by means of the electro-polarization of the constituent atoms of conducting bodies, and the *identity of thermo-electrical and mechanical action* (page 348), even to the welding together of pieces of iron beneath cold water.

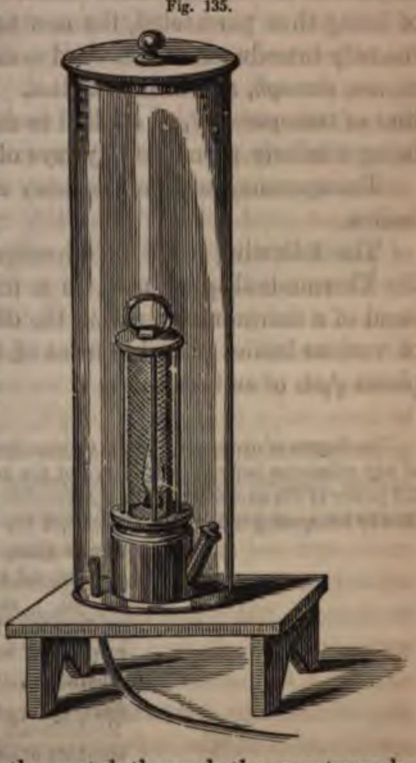
The electro-dynamic action in the form of heat becomes propagated through imperfectly conducting bodies, with a very slow, but nevertheless with a very certain progress, in continuously extending closed circuits, producing molecular vibrations; and if there be a continuous propagation of this action through an imperfectly conducting body, the intensity of the excitation becomes finally extended uniformly throughout the mass. The sides of the brickwork of furnaces of steam-boilers, when left uncovered and free to propagate the electro-dynamic action to the adjacent air, render commonly manifest very slight warmth to the hand. But when the surfaces of such brickwork are covered with cotton, wool, pine boards, and other non-conducting materials, as is frequently practised to dry these materials, the cessation of radiation from their external surfaces finally produces an equalization of the temperature of the external and internal parts of the furnace. Frequent cases have come to my knowledge where such materials have been thus ignited, causing destructive losses by fire.

The same results occur when the wooden beams and casings are fixed against chimneys or adjacent to hearths. If the heat be continuous, the safety of buildings becomes thus endangered.

In the experiments which have been illustrated by the instrument shown at page 350, a continuous propagation of the electro-dynamic action in the form of heat is radiated through the air, in the same manner as light is radiated in straight lines.

Were it not for this continuous propagation of the electro-dynamic action from the mass of the earth in the form of *radiant heat*, the intensity of its excitation might finally become so much augmented, like the non-conducting covered brickwork just described, as to ignite the combustible materials on the earth's surface.

Fig. 135.



The wires of Davy's safety lamp serve as conductors to propagate the electro-dynamic action of the burning gas faster than it is developed in the specific form of heat and thermo-electric currents. By this reaction the further recoil of the atoms of the carburetted hydrogen to their natural static condition of carbonic acid gas is instantaneously arrested. Instead of the meshes of wires arranged around the burning candle, as represented in the figure, the danger of explosion in the use of the oxy-hydrogen blow-pipe is obviated by causing the jet of gas to pass through a tube filled with fine wires. The contact of the gas with the metal through the apertures between the wires, effectually electro-polarizes the atoms of the gas, and prevents the extension of the process of combustion through them.

THE RADIATION OF HEAT is effected through void space, or through space occupied by certain kinds of solid bodies. A similar direct propagation of electro-dynamic action is effected through a sheet of glass (figure 56, page 282), and even through opaque bodies, as described of the action of conducting wires through a partition wall or door (page 381). This mode of propagation of electro-dynamic action has been denominated "Inductive Excitation." It might with equal propriety be termed *radiation* of electricity. It is the action, not the matter, which is propagated through space.

To distinguish bodies capable of being readily permeated by the action of "radiant heat" from those which are not capable of being thus permeated, the new term "Transcalent," has been recently introduced. This word is derived from the Latin words TRANS, *through*, and CALEO, *to heat.* The term corresponds with that of transparency, as applied to characterize bodies capable of being similarly permeated by rays of Light.

Transparency and Transcalency are not the same in the same bodies.

The following table of experiments, made by Melloni with the Thermo-multiplier used as a test (figure 87, page 351), instead of a thermometer, shows the difference of the Transcalency of various bodies placed in front of the screen r, and reduced to plates $\frac{1}{10}$th of an inch thick.

The degree of divergency of the Galvanometer needle, without the intervention of any substance before the aperture of the screen, being taken to represent the full power of the excitation of the thermo-electric current,	=	100
then by interposing a thin plate of rock salt, the divergency became decreased to		92
mirror glass,	"	62
rock crystal and Iceland spar,	"	62
do. smoky and brown,	"	57
carbonate of lead,	"	52
sulphate of barytes,	"	33
emerald,	"	29
gypsum,	"	20
Rochelle salt and alum,	"	12
sulphate of copper	"	0

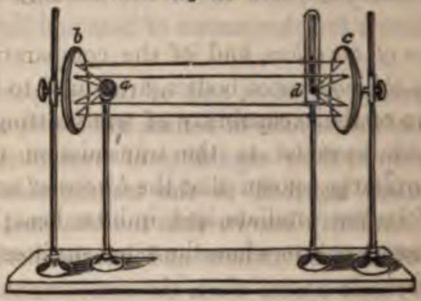
The action induced during the excitation of bodies by the cause of the phenomenon of heat, has been more recently experimented upon by Professor Forbes, who has succeeded in exhibiting the phenomenon of "polarization of Heat," by every method which serves to exhibit the "polarization of light;" viz., by reflection, refraction, and double refraction. As the polarization of bodies has been shown to be the result of all electric excitations, this discovery appears to be the last link wanting of the chain that connects the phenomena of heat and light with electrical causes.

The differences of the colors, and of the comparative *roughness* and *smoothness of the surfaces* of bodies, are found to have an intimate relationship to their capability of transmitting the electro-dynamic impulses ascribed to the transmission of Heat and Light. It is familiarly known that the *blackened* and the *roughened* surfaces of bodies "radiate and imbibe heat;" whilst the reverse of this result occurs when the same surfaces are *whitened* or *smoothly polished.*

It has been previously noticed that the mere circumstances of dyeing to a *black* color a piece of *white* silk ribbon, and of the grinding to a rough surface a piece of glass preparatory to subjecting them to the process of friction for mechanically exciting electricity, is sufficient to change entirely the character of the electro-dynamic action, by producing exactly opposite movements of the pith balls or gold leaves of the instruments used as electroscopes. These instrumental tests thus render manifest the excitation of more or less intense, or even of directly opposite, electrical forces and currents. Thus, so far as the character of the comparative roughness and smoothness, and of the colors of bodies are concerned in the excitation and transmission of the mechanical forces ascribed to Heat and to Electricity, there appears to be also an intimate relationship, if not an identity.

Supposing the existence of an universal diffusion of electricity, or rather of a shoreless and bottomless all-pervading ocean of this subtle fluid atmosphere, such as has been previously suggested in describing the simultaneous movements of magnetic needles in observatories on distant parts of the earth's surface, the phenomenon of heat may be ascribed to the mechanical action of undulatory waves of such an elastic medium; in the same manner as sound is propagated, and also in accordance with the undulatory theory of the propagation of light. This has been compared to the propagation of the sound of the ticking of a watch placed in the focus *a* of one of a pair of concave reflecting mirrors *b c*. The waves of air emanating from the percussion of the mechanism as from a focus, are reflected in parallel lines from the concave surface of the mirror *b* to the opposite mirror *c*, as shown in the figure; from the concave surface of which the waves of air are again reflected and concentrated to the point or focus at *d*, where the mechanical action on the membrane of the ear is most powerfully augmented in intensity.

Fig. 136.



The impulse of a *mechanical action* producing the *movement* of matter is assumed in all three of these cases to be standard tests; but the one is popularly ascribed to the presence of an independent agent, "heat," the second to a distinct imponderable agent, "electricity," and the third to the agency of a ponderable fluid, the "air."

By using numerous mirrors with flat surfaces to combine the solar radiations on one object, Buffon succeeded in radiating sufficient heat to melt a quantity of lead placed at a distance of 140 feet, thus verifying the practicability of the attempt of Archimedes to set fire to the hostile fleet in the harbor of Syracuse.

The preceding analogies admit of being farther extended to demonstrate the identity of the propagation of the action of "Heat" and of mechanical action through the medium of electric matter. The source of this excitation has been previously traced

to the originating source of solar action in treating of Thermo-Electricity.

PROPAGATION OF MECHANICAL ACTION THROUGH THE MEDIUM OF ELECTRIC MATTER IN THE FORM OF—

LIGHT.

The subject of the excitation of Electricity by Light, or Photo-Electricity, has previously been adverted to very briefly, at page 360. In treating of the subject of "Light," the converse of the preceding course of investigation is to be pursued. Both Heat and Light have been shown to induce electrical excitation. It remains now to be shown that Electric excitation—that is, the propagation of mechanical impulses through the medium of electric matter, produces the phenomenon recognizable as that of Light, as has just been done in regard to the phenomenon of Heat.

In commencing the analytical investigation of Heat, a review was first presented of the popular doctrines taught in relation to this branch of physical science. The same course will be adopted in relation to Light.

Two theories of Light have been advanced, denominated *Radiatory*, and *Undulatory*. The former. teaches, that luminous bodies dart off in all directions particles of inconceivable minuteness, capable of traversing space, and of producing sensations or perceptions of Light. The latter ascribes the phenomenon of Light to mechanical causes, producing vibrations of a subtile ethereal fluid pervading all space. The vibrations of this fluid are supposed to extend to the nerves of the eye, like those of air, which extend to the nerves of the ear, producing perceptions of sound in the one case, and of light in the other. The cessation of the vibrations of the subtile ether represents *darkness*, as the cessation of the vibrations of the air represents silence.

The parallel has been carried out still farther; for as the sensations of the harmony of sounds of the musical scale are produced by the more or less frequent vibrations of the air in contact with the ear, so the harmony of colors has been supposed to be produced by the more or less frequent vibrations of this subtile ether in contact with the nerves of the eye. The strings of musical instruments, it is familiarly known, vibrate more slowly or rapidly in proportion to their thickness and state of tension, the tightest and finest evolving the sharpest notes, and the thickest and loosest the lowest notes. In like manner it has been supposed that the impressions of distinct colors of violet, scarlet, yellow, &c., are produced; and Sir John Herschel has even gone so far as to compute the number of vibrations of the undulatory ether which are required in one second of time to produce the several sensations of the different colors.* "Every point of a medium, through which a ray of light passes, is affected with a succession of periodical movements, regularly recurring at equal intervals. It is by these movements, communicated to the nerves of our eyes, that we see. Nay, more; that it is the difference in the frequency of their occurrence, which affects us with the sense of the diversity of color. In receiving the sensation of redness, our eyes are affected 482,000,000 of times; and of violet 700,000,000,000, of times per second."

Another writer, in extending the application of this principle, has observed, that "it may even be calculated, that if a string of a musical instrument, of the proper length to produce a sound corresponding to the note of the middle C of the piano, were bisected 40 times, it would, supposing it was still possible to make it vibrate, evolve—not a sound,—but a *yellowish green light.*" *!*

Still following up this undulatory theory, it has been further observed that, "colors are consequently no more innate properties of bodies than any particular sounds or notes are."†

This *undulatory* theory, as it is termed, is capable of affording a ready solution to explain certain phenomena of Light, which the theory of emission of rays fails of explaining; and on this account it has received the approbation of many very eminent men; but like the theory it was intended to supplant, it is also objectionable, from its failing to explain many other most important phenomena. The introduction of it seems to have accomplished the purpose, however, of effectually unsettling the previously established belief in the Newtonian theory of Radiation.

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*Young's Lectures on Natural Philosophy. †Nat. Phil. Golding Bird, page 314.

The third theory of Light has been proposed by the celebrated Oersted, who considers it as produced by a series of electric sparks. This latter theory, it has been stated by a late writer, is adopted by a few advocates.*

Berzelius advanced a theory of Light and Heat producible by combustion, founded on the supposition that "these phenomena are observable as the consequence of the transference of electricity between the atoms combining together." In commenting on this suggestion Professor Faraday remarks, "this transference of electricity may be classed with the great mass of doubtful knowledge."

Mr. Faraday affirms, "that we do not know as yet enough of electric light to be able to state on what it depends; and it is very possible that, when electricity bursts forth into air, all the particles of which are in a state of tension, light may be evolved by such as, being very near to, are not of, those which actually receive a charge at the time." (Experimental Researches, page 461.) It is difficult to comprehend, from this explanation, the meaning of the distinguished experimentalist.

In speaking of the light exhibited by the radiations from a pointed conductor, termed a *brush*, he continues, "I may state, that it is a spark to air; a diffusion of electric force to matter, not by conduction, but disruptive discharge; a dilute spark, which, passing to very badly conducting matter, frequently discharges but a small portion of the power stored up in the conductor," &c. These sentences convey also an imperfect conception of the views of this eminent man in relation to the Light observable on the transit of electricity through the air.

According to Melloni's opinion of the mode of action of light and heat, he concludes, "that the molecules of bodies, slightly heated, vibrate slowly, and produce long and invisible waves in the ethereal medium which surrounds them." Near the point of incandescence "the ponderable particles commence to vibrate more swiftly than the rest, and produce in the ether shorter undulations, which are consequently more refrangible; and of which some become visible, until at last a great number of elements of luminous and obscure heat are found united in the radiant flux from sources of high temperature."

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*The details of this theory I have not been able to procure.

Dr. Hare gives the following *Rationale of Electric Light and Ignition.*

"It appears evident that there is a reaction between heat, light, and electricity. It is not surprising, therefore, that the presence of one should cause the appearance of the others, since they all evidently pervade nature. It may be conjectured that the electric fluid is luminous when projected with intensity into the air, in consequence of its carrying along with it the light encountered in its progress through ponderable matter. In like manner it may cause the extrication of caloric, by displacing it when latent; or by adding temporarily to its repellent power, it may enable it to overcome the attraction of cohesion; in which case a metal, no doubt, contains caloric enough to produce a violent, or even explosive separation of the metallic particle."*

The names of the most eminent philosophers of ancient and modern times, are arranged on each side of this debatable question.

The materiality of Light has been maintained by PYTHAGORAS, LUCIPPUS, PLATO, EPICURUS, NEWTON, BREWSTER.

The contrary has been maintained by HUYGHENS, HOOKE, EULER, YOUNG, SIR JOHN HERSCHEL, ARAGO, and other eminent modern philosophers.

And it still remains also a subject of discussion whether the sun's rays, or white light, be composed of *seven* primitive rays, as supposed by Newton, or of only *three* essential constituent kinds of rays, as Sir David Brewster has labored to prove.

The philosophers who have maintained the undulatory or wave theory, have also differed among themselves as to the essential composition of the rays of light, Hooke asserting the existence of only *red* and *violet* rays; Huyghens, of only yellow and blue; and Young, of *red*, *green*, and *violet*.

In connection with the preceding theories of Light, a few of the principal objections to them which have been urged reciprocally by the opponents of each theory, will here be noticed.

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* Hare's Chemistry.

To the theory of the emission of minute particles darting out from luminous bodies in all directions, as suggested by Newton, there is the objection of involving the necessity of a continuous supply to the orb of the sun of some kind of material fuel to maintain the continuous supply of the light-producing or lucifer matter, continuously emitted, as men add combustibles to sustain beacon fires on mountain tops.

Mr. Whewell observes that the *undulatory theory* leaves the whole subject of colors, both in opaque and transparent bodies, involved in profound obscurity. It does not serve to explain how the chemical changes in bodies are permanently produced by the action of light in inorganic, and more especially in organic matter, as essential to the existence of the vital principle.

"The waves of all known elastic fluids extend around the corners of interposed bodies, and through crooked tubes. The undulations of the air, in the science of acoustics, are familiarly caused to become bended out of straight lines in the crooked tubes of various musical instruments, such as the French horn, bugles, &c., and with peculiarly delightful effects on the sense of hearing. The undulations of light, on the contrary, are not propagated through crooked tubes at all."

The undulatory theory does not explain "the generation of *light* by combustion, ignition, friction, and percussion; nor how it is connected with caloric, and electricity, nor *why ponderable matter* is *essential to its production.*"

"That in adopting the theory of *undulations*, we are called on for acts of faith, and certain admissions to be made at every step, is acknowledged by Sir John Herschel, who is certainly one of its ablest advocates."

Mr. Griffin, in his Scientific Miscellany, observes, "it is extremely difficult to explain many of the phenomena of light by either of the rival theories; and as we proceed in our inquiries, the question of the materiality or immateriality of light becomes more and more complicated."

As so many important static and dynamic conditions of the groupings of atoms of terrestrial matter are essentially connected with the influence or cause of Light, it would leave a gap in our course of investigations to pass hastily over this much controverted question. A strictly mechanical view of the phenomena, popularly ascribed to the influence of "Light," will therefore be taken, as being devoid of abstract theoretical speculations. In pursuing this course, it will not come within our province to discuss the comparative merits of the preceding discordant theories, which are sufficient to teach caution in adventuring new opinions, whilst at the same time they warrant a careful attempt to arrange a systematic train of well-established facts.

The difficulty which has hitherto embarrassed these investigations of the phenomena of Light, appears to have originated from an omission to notice the differently modified forms in which impulses of mechanical force may become propagated through the medium of electric matter. By various stages of static and dynamic-conditions of groupings of elementary atoms at sensible and insensible distances, these differently modified forms of propagation may be consistently and rationally explained.

In considering the course of the continuous propagation of the electro-dynamic action of the sun in the modified form of Heat, most of the facts and suggestions that apply to our present subject of investigation have been anticipated. It has been shown that there cannot take place the movement of one body toward or about another, without producing a disturbance of the electro-static condition of both bodies, and the consequent propagation of electro-dynamic impulses; and no other reason for originally imparting the rapid movements of the huge orbs of matter about the central orb of the sun in the free space of the heavens is imaginable, unless it be this special design of propagating the original impulses in the variously modified forms of the mechanical action of Heat, Light, &c., which finite intelligences comprehend by the term "Natural Motive Power."

The mechanical movements of the mass of the earth about the sun, it has been narrated in treating of terrestrial magnetism, induces the continuous circulation of electric currents about the earth's surface in a direction from east to west, and occasions the movements of such currents in visible flashes of the Aurora Borealis in the lofty regions of the earth's atmosphere transversely to the equatorial currents, in north and south directions. Were these electric currents constantly prevailing in the elevated regions of the earth's atmosphere, there can be little doubt that our now opaque orb would present to the eye of a human being in one of the adjacent orbs of the solar system, a luminous, radiant appearance, having resemblance to the light of the sun.

The continuous propagation of electro-dynamic action from the sun to all terrestrial matter, and to the nerves of the eyes of sentient beings, constituting electroscopic groupings of atoms of such matter, is ascribable (page 311) to the impulses imparted by Almighty Power to the huge masses of the orbs which revolve about it in the free space of the heavens; and hence electro-dynamic science teaches us, that so long as the planets continue to move about the great central orb, so long will that central orb continue "to shine."

The most intense light which can be artificially excited, is producible by means of an electrical current from a galvanic battery. The following interesting account is given of the intense excitation of light by an experiment with the powerful galvanic battery of the Royal Institution, composed of 2000 pairs of plates.

Upon each of the ends of two conducting wires, composing the circuit of this battery, was fixed a piece of charcoal cut to the shape of a slender pencil, each of the length of about an inch, and of the diameter of about $\frac{1}{6}$th of an inch. When these charcoal points were brought within a distance of about $\frac{1}{30}$th of an inch of each other, a vivid spark occurred; and by subsequently withdrawing the points to a distance of about 4 inches asunder, a continuous current rushed through the heated air between them, forming an arch of light (see figure 77, page 329) of considerable breadth, and of the most dazzling brilliancy. The light produced by the stream of galvanic electricity in its transit through the space of air between these charcoal points was so vividly bright as to overpowêr the sense of sight, like the beams of the sun. Even a momentary glance caused the spectator to shade his eyes with his hand almost involuntarily. "By its superior lustre it effaced the light of lamps in an apartment otherwise brilliantly illuminated, and which appeared to be shrouded in comparative darkness when the galvanic light suddenly ceased. It is, indeed, a light that so nearly emulates the brightness of the sun's rays, as to be applicable for the purpose of successfully illuminating objects for examination by a solar microscope."

The prismatic colors become perfectly developed by means of a galvanic battery.

The light produced by 300 pairs, Dr. Hare states, "resembled sunshine on some buildings adjacent to the windows of the laboratory." The eyes became inflamed on steadfastly regarding the intense electrical light between two charcoal points, and even the skin of the face, according to Mr. Daniell's statement, became also inflamed, as if it had been exposed for many hours to a bright midsummer's sun. "These rays when reflected from an imperfect parabolic mirror of a lantern, and collected into a focus by a glass lens, readily burnt a hole in a paper at a distance of many feet from their source."

When a piece of fine wire gauze was held before this flame as a partial screen to a sheet of paper previously steeped in a solution of nitrate of silver, a complete pattern of the meshes of the wire appeared in white lines, corresponding to the parts which it had served to screen. It has been noticed at page 478, that the flame of a lamp rotated about the top of a magnet held near it. It has been found that the electric flame from the pole of a magnet included in the circuit, "*rotated in a beautiful manner*;" thus demonstrating also in this respect a complete identity.

Since the discovery of the brilliant illuminating powers of the flame between two approximated poles of a galvanic battery, numerous attempts have been made to render this source of illumination available for the useful purpose of lighting buildings. It truly appears at the present time too late to attempt mooting the question of the identity of electrical light, and of that propagated from direct solar radiation and from combustion, after letters patent have been issued in England for the use of improved arrangements for rendering this mode of illumination a substitute for the combustion of oil and gas.

The patentee, Mr. Staite, has published the following account of the comparative illuminating power and economy of "Electrical Light," and of that attainable from the combustion of gas and candles.

"With a battery consisting of four small cells, a light was developed equal to 380 mould candles (sixes), or 300 wax candles, or 64 cubic feet of the best gas burnt in a standard burner. This was effected by a consumption of zinc equal to $\frac{77}{100}$ths of [illegible] nd, being little more than $\frac{3}{4}$ lb. of zinc per hour."

"By increasing the distance between the charcoal points to their limits, the light was increased nearly threefold; whilst the current itself was reduced to about ⅗ths in quantity."

"This curious fact," continues Mr. Staite, "I have frequently observed before. The light, when developed under the best circumstances consistent with its permanency, was produced by a consumption of ⅐th part only of a pound of zinc per hour; and that light equal to 380 tallow candles. Assuming that the zinc so consumed was worth one half-penny, and that the cost of the working solutions, deducting the value of the products, was as much more, we have the following comparative result: Electric light, 1 penny per hour; gas light equal thereto, 6 pence to 8 pence; tallow candles, 7 shillings and 6 pence; wax, 12 shillings."

Such are the flattering prospects which this sanguine experimenter holds out in favor of rendering the immediate dynamic action of electricity on the nerves of the eye a substitute for the ordinary modes of burning gases, oil, &c., for purposes of illumination.

The fact of the intense excitation of the phenomenon of light caused by the introduction of a piece of lime into the dim flame of a jet of burning hydrogen gas, to produce the dazzling glare of the "Drummond Light," merits attention here, as being an evidence of the necessity of the presence of solid matter, to develope electro-mechanical action and reaction. It has been affirmed that as neither light nor electricity can exist separately from matter, that "they are not material, and are consequently only the properties of the matter in connection with which they become manifest." But this fact, so far from proving the immateriality of the electric fluid, may be considered as one of the strongest proofs in favor of its materiality. There must be intense electric action to induce intense effects of the phenomenon of light. But in accordance with the laws of mechanics, there cannot be action without reaction, or without something to be acted upon. When the piece of lime is held in the nearly invisible flame of the commingled jet of hydrogen and oxygen, there is presented a material point of reaction to the electric action. To affirm, therefore, that light cannot exist independently of matter, is merely equivalent to affirming that action cannot take place independently of reaction.

Were there no steadfast rock to breast the rushing stream, no shore to react against the heaving billows, the white foam and roar of the cataract and of the ocean surge would be unknown. There must be matter standing in the way of moving matter, to develope mechanical action and reaction.

Phenomenon of the TRANSPARENCY of bodies, or the propagation of the electro-dynamic action through solid bodies in the form of light.

Although a sheet of transparent glass may be impervious to the direct passage of an electric current through it, yet it has been shown at page 364, figure 37, that the propagation of electro-dynamic impulses is not limited to that side of the sheet on which the electric excitation is produced; but, on the contrary, the inductive action is propagated as instantaneously through a sheet of glass, as if the electric spark did actually pass through it. By holding the palm of the hand against one side of a sheet of glass, and by presenting the opposite side of the sheet to the knob of an excited conductor of an electrical machine, every spark, which passes from the knob to the adjacent surface of the glass, will be felt by the nerves of the hand as energetically, as if the glass had not been interposed between the knob and the hand.

In the preceding experiment, had we simply trusted to the sensations of feeling caused by the inductive excitation of the nerves of the hand, as an electroscopic test of the passage of the electric spark through the sheet of glass, we might pronounce the glass to be as permeable to electricity, as we pronounce it to be to "rays of light," taking the sensations of *seeing* and *feeling* caused by the inductive excitation of the nerves of the eye and of the hand to be similar standard electroscopic tests.

So in regard to the propagation of the "rays of light," through the sheet of glass, all we know is the fact of precisely the same propagation of electro-dynamic action. Indeed this analogy affords the most conclusive reason for the belief, that the propagation of light is identical with that of the propagation of electro-dynamic action; and that no material "ray of light" ever yet passed through the glasses of a telescope upraised toward the luminaries of the heavens.

By the powerful electric excitation, or electro-polarization of bodies, their relative states of opacity and transparency become essentially varied. The most opaque substances are found to become resolved into *transparent* gaseous states, by the intense excitation of the powerful electric flame between the two poles of an extensive galvanic battery. It has been supposed, as before suggested, that the whole material terrestrial globe might become resolved into vapor, as transparent as the air we breathe, and that the elements of rocks and mountains might thus float in the firmament in such a state of separation, by means of the physical impulses of electro-dynamic or electro-polarized action, that the light of the feeblest shining star might not be obscured thereby, any more than it is by the nebulous vapor of a comet.

When most kinds of bodies are left to return gradually to their natural state of solidity, they cease to be transparent; but when suddenly deprived of their thermo-electrical excitation by being rapidly cooled, many of them retain very remarkable properties of transparency. Thus, sugar, sulphur, &c., when suddenly cooled, after being melted, become transparent. But after a certain time, when left to themselves, they become crystallized and opaque; thus demonstrating that even when the component atoms of bodies have been brought together by what has been termed "Cohesive Force," they are still subjected to the further ultimate re-arrangement under the action of electro-dynamic forces, which reduce them finally to a crystalline opaque condition. Even transparent glass when kept soft for some time by heat, becomes opaque and white.

The propagation of light through transparent bodies is affected by the magnet, according to the result of experiments made by Professor Faraday. This fact shows that the propagation of electro-dynamic action, producing the phenomenon of light, is controlled by the same laws as those of electro-magnetic action.

Professor Plücker states, that by means of a magnet we may find the optical axis of a crystal, although it may be neither transparent, nor exhibit any trace of its crystalline structure. At the same time we get a new proof of the connection between "Light" and magnetism; for when light is passing through a crystal, there are in general two directions, wherein it is effected in quite distinct ways;—magnets act upon them in these same directions.

It is a law of optics, that the angle of reflection of light from a mirror is equal to the angle of incidence.

This law establishes the perfect identity of the propagation of "light," and of mechanical action; for the incidence of the "ray" represents the incidence of an impulse, and the equal angle of resilience shows the never-failing equality of the mechanical reaction.

These, and numerous other facts which our limits debar noticing, demonstrate that the propagation of light from luminous bodies, through transparent bodies, to the sensitive nervous tissues of the eye, is controlled by the same laws which govern electro-dynamic action; and hence we may infer that the transparency of bodies may be the result of the propagation of this same electro-dynamic action through the medium of electric matter.

Various modified forms in which the mechanical action of Light becomes propagated through the medium of electric matter.

Human intelligence takes cognizance of the phenomena popularly ascribed to Light, by means of appropriate nerves located in the organ of the eye. In treating of Heat, it has just been shown that the phenomena popularly ascribed to this "Imponderable Agent," are in like manner taken cognizance of by sentient beings through another set of nerves distributed over the body. In treating of the Nerves of Sensation, considered as electroscopic tests (page 193), it has been noticed that the propagation of electric action through a piece of fine wire has been designated by the three distinctive names of *heat*, of *light*, and of *electricity*, according as the electro-mechanical action may be exerted upon the electroscopic nerves of the hand—of the eye, and of the muscles connected with the brain by the motor nerves, producing muscular contractions and consequent *animal motive-power*.

Were not sentient beings endued with optic nerves, the gradually increasing temperature of the conducting wire ignited by a galvanic battery, would be unhesitatingly ascribed to the cause of electric excitation. The fact that different electroscopic apparatus are necessarily employed, for the security of animal mechanisms, as standard tests of the intensity of the excitation of bodies, cannot affect the nature of the causes producing the excitation. And as it has been established that every cause of electric excitation is capable of producing in the electroscopic nerves of the eye the sensation of Light, there appears to be no sufficient grounds for hesitating to ascribe all the phenomena of Light to the propagation of mechanical action, through the medium of the perfectly mobile electric matter occupying all the space not occupied by other matter.

In describing Magnetic Observatories, it has been noticed that a cause of electric excitation on one part of the earth's surface is sufficient to propagate the electroscopic action to the compass-needle situated on all parts of its surface. A disturbance of the universally diffused electric ocean in the remote depths of space occupied by the stars, is in like manner appreciable by the more delicately sensitive electroscopic nerves of the eye, which are specially adapted to receive the action of impulses thus propagated.

It is difficult for finite intelligent beings to form an adequate conception of the attributes of a *perfectly mobile fluid medium*, such as the electric medium pervading all otherwise unoccupied space manifestly appears to be. It admits of being best conceived of, by adhering strictly to the meaning of the words employed in Mechanical Science to define the perfect passiveness of matter, viz.: Matter, when put in motion, cannot stop itself, nor turn aside in its course from a straight line.

The perfectly fluid electric matter, when put in motion by any cause, cannot stop itself. It must therefore continue to move, and propagate indefinitely, or infinitely as it regards time, the impulse it may receive. Thus, an undulatory wave of the shoreless ocean of electric matter may continue to be propagated through infinite space during thousands of years, as is affirmed by astronomers to be the case of the propagation of light from distant stars to the speck of terrestrial matter on which we find ourselves existing.

Before the undulatory theory of Light can be with confidence adopted, it becomes necessary to answer the objections to its truthfulness, which have just been urged against it, affirming, that the undulating waves of the electric ether should become propagated through a crooked tube to the nerves of the eye, as the undulatory waves of the air are propagated through the same tube to the nerves of the ear. It is necessary clearly to trace out the continuous propagation of the mechanical action of "a ray of Light" from its entrance into the orifice of the tube, until it again appears, or comes out therefrom, in order to establish the fact that it is not "lost."

Considering a ray of Light to represent a mechanical impulse, propagated through the medium of electric matter, it must continue to be propagated as indestructibly as matter itself. An impulse may be counterbalanced by another impulse reacting in an exactly opposite direction, and thus it may be neutralized; but it is nevertheless not annihilated. It will appear again in the resolution of some resultant force, as in the resolution of groupings of atoms from static to dynamic conditions, as has been recapitulated in treating of organic and inorganic formations.

The most conclusive proof of the identity of *light* and of *mechanical action*, is afforded by the "interference of the rays of light; whereby two pencils of light may produce *perfect darkness*," or be made to "produce increased light," at the pleasure of the experimenter.

This result may be readily anticipated from simply changing the directions of the action of the impulses to *oppose* each other, or to *coincide with each other*.

The former represents a static condition, the latter a dynamic combination of mechanical impulses, acting in coinciding directions, and correspondingly augmenting the resultant action.

The first objection to the undulatory theory of Light affirms that light, or the electro-dynamic action of the sun, should be propagated through a crooked metallic tube.

We will suppose the solar rays to be concentrated powerfully by a concave mirror, and directed into the cavity of one end of a crooked tube. It will be found that if the electro-dynamic action be not propagated through the tube by reflections from its interior burnished sides, to reach the electroscopic nerves of the eye applied to the opposite end, that they will certainly reach the electroscopic nerves of the hand, which grasps the tube, in the form of Heat. It has been stated (page 43), that the electroscopic nerves of feeling are adapted to taking cognizance of slight degrees of electro-dynamic action propagated in the specific form of Heat, through a fine conducting wire held between the thumb and finger, whilst the electroscopic nerves of the eye take no cognizance of this slighter action; and that the optic nerves are not therefore designed to serve as electroscopic tests of the propagation of electro-dynamic action, which the nerves of feeling (page 188) are adapted to recognize.

But when the solar action is intensely concentrated by a large concave mirror, as before stated, and directed into the cavity of the crooked tube, it will be speedily found that this electro-dynamic action will not only be propagated to the nerves of the hand, but also to the nerves of the eye, by the incandescence of the sides of the metallic tube.

These facts demonstrate conclusively, that the propagation of mechanical action in the specific form of Light, directed into the interior of a crooked tube, becomes resolved into molecular vibrations constituting the phenomenon of Heat. They show that the true difference between Light and Heat simply consists in the difference of the modes of propagation of mechanical action, through the medium of electric matter, to two distinct arrangements of electroscopic nerves,—those of the eye, and those distributed over the surfaces of animal bodies.

When the nerves of the eye and those of feeling are brought into contact with electrically-excited bodies, as with the connecting wires of galvanic batteries, perceptions of Light are recognizable by the one, of Heat by the other (page 191). The former has been denominated the *communication of Heat by conduction.* The latter may with equal reason be termed the *communication of Light by conduction.*

The nerves of feeling are also susceptible of excitation by the radiation of electro-dynamic action from incandescent bodies, like the nerves of the eye. In the one case, however, the phenomenon is denominated RAYS OF HEAT, in the other, RAYS OF LIGHT.

The communication by contact, and through the electro-polarizations and molecular vibrations of atoms, is equivalent to Electric Conduction; that by radiation, to Electric Induction.

These explanations are necessary to disembarrass the subject of the complexity in which it is involved by the use of different names and terms to indicate the same cause, and identical effects.

The *Conduction* both of Heat and Light is a more sensitive mode of propagation of electro-dynamic action to the electroscopic nerves than their *Radiation*, as may be tested by placing a Thermo-electric Multiplier (figure 86, page 350), in the mouth of the crooked tube, and by extending the connecting wires to the corners of the eye applied to the opposite extremity. However crooked may be the tube, the electro-dynamic action becomes appreciable by the nerves of the eye in the modified action of a flash of light, on making and breaking the contact of the connecting wires. This fact shows that "light," like "heat," may be communicated by Conduction as well as by Radiation.

The REFLECTION OF LIGHT AND HEAT is a mechanical rebounding or resilience of the undulatory waves of electric matter, which affect the mass, but not the molecules of the body impinged upon, the electro-polarizations remaining unchanged. Were the electric matter sufficiently ponderable to propagate any discoverable momentum, the Reflection both of Heat and Light would be discoverable in the recoil of the mass of the mirror, from the surface of which the electric waves are thrown back, as the yielding vessel recoils from the shock of ocean waves.

When the rays of light are perfectly thrown back from a metallic reflector, it remains cold; no molecular vibrations, constituting the phenomena of heat, being discoverable. When they become apparently lost by entering the blackened surface of the same mirror, they are immediately traceable in the molecular vibrations, recognizable as Heat.

If within the interior of the crooked tube there be arranged mirrors at right angles to each other, the electro-dynamic action might be propagated to the nerves of the eye through a bended tube without affecting the nerves of the hand, in the modified form of Heat.

By varying the arrangement of the relative angles of mirrors to 56°, as is accomplished in the tubes used for *polarizing light*, they cease to perform the functions of mirrors. The ray of light is then said "to be lost" by its polarization. But this polarized ray still continues to be traceable in the form of heat imparted to the mirror itself, which would have remained cold were the rays of light reflected from its surface.

The similar polarization of light, which takes place by refraction of various transparent crystals, such as Iceland Spar, as well as by the double reflection of two mirrors, it has been stated, is prevented by the action of powerful electro-magnets on the crystal, and the lost ray is thus restored to its usual line of refraction.

Instead, however, of ascribing the non-reflection of the lost rays to their polarization, it may rather be ascribed to the peculiar angle of incidence relative to the polarization of the constituent atoms of the mirrors, upon which the electro-dynamic action takes effect, instead of being glanced therefrom by a resilient reaction. In the former case their molecular polarization becomes affected; in the latter there is simply a case of mechanical action and reaction.

So far, then, is the propagation of vibrations of the electric matter from differing from those of the elastic medium of the atmosphere, in the propagation of sounds through crooked tubes, that there may be traced a very exact analogy between them, by simply taking into consideration the Protean changes or modified forms, in which the action admits of being propagated.

A beautiful illustration of the preceding principles is afforded by actual experiment of the propagation of mechanical action through the crooked tube of brass, by means of atmospheric fluid air, instead of the electric fluid, in the modified forms of heat and of light.

When the mechanical action of the breath is caused to propagate sounds through a brass bugle, a portion of the action is expended against the sides of the instrument, producing the vibration of its component atoms, which augments the mechanical ringing action on the external air, in addition to the action propagated from the mouth of the instrument. This vibration is appreciable by the nerves of the hand, like the molecular vibrations producing the sensation of heat.

But if instead of employing the feeble power of the human lungs a very powerful forcing syringe be substituted, and the mouth of the bugle be closed, the mechanical action, propagated through the elastic medium of the atmospheric air to the sides of the metallic tube, induces therein molecular vibrations recognizable by the hand grasping it, as the phenomenon of Heat. And when the mechanical action is very intense, an electro-dynamic excitation takes place, which kindles tinder placed beneath the piston, as is familiarly known in the once common use of a similar apparatus, substituted for a flint and steel in kindling tinder. At the same time flashes of light occur, it has been stated, which act on the electroscopic nerves of the eye, applied to a glass at one end of the tube.

By arranging electroscopic instruments within the cavity of a tube thus used for propagating powerful impulses of mechanical force to the fluid medium of the air, the mechanical action becomes propagated to these instruments in a form which is indisputably recognizable as excited *electricity*.

These experiments conclusively demonstrate that mechanical action may be successively propagated through the medium of the fluid particles of atmospheric air to produce all the phenomena recognizable by mankind, as Heat, Light, and Electricity; and that a *mechanical action admits of being propagated, even thrbugh a crooked tube*, to extend impulses to the retina of the eye, recognizable as *Light*.

In illustrating the fact of the propagation of the electrodynamic action of the sun in the form of *heat* (page 353), it has been previously noticed that by means of the small thermo-electrical apparatus applied to the point where the eye-glass is inserted in the tube of a reflecting telescope, "the differences of radiation from small objects at the distance of several miles, are detected," the needle of the appended galvanoscope becoming moved by the differences of radiations propagated "even from different parts of the clear sky."

By this exceedingly interesting experiment it appears to be conclusively demonstrated, that the same instrument,—the telescope, which is employed to propagate the modified electro-dynamic action in the form of "light," to the electroscopic nerves of the eye, serves also to propagate electro-dynamic action to deflect the needle of a regular galvanoscope. The movements of the needle, and of the contracting pupil of the eye, are alike mechanical effects produced, and alike tests of the propagation of mechanical action through the medium of electric matter in the form of Light.

Although the rays of Light are found by Sir John Herschel to be refracted at a different angle from those of Heat, on being transmitted through a prism upon a table, yet the only argument that can be adduced from this fact, to contravene the absolute identity of the electro-dynamic action of the sun constituting the phenomenon both of heat and light, is a difference of *divergency of the line of action*, and of *intensity of action*, on being propagated through transparent media. There is nothing in all this to show any absolute difference in the nature of the action induced;—it is electro-dynamic action still, or mechanical action, propagated through the medium of electrical matter, and variously modified by the electro-polarized groupings of atoms of transparent bodies.

Electro-Dynamic Theory of Colors.

It has been also objected (page 623), that the undulatory theory of Light "leaves the whole subject of colors both in opaque and transparent bodies involved in profound obscurity," and that it does not "serve to explain how the chemical changes in bodies are permanently produced by the action of light on inorganic, and more especially on organic matter."

The changes of colors of the organic matter of various vegetable infusions, such as those of blue cabbage, mosses, litmus paper, &c., from a blue to a red color, and from red to bluc, by successive additions of a preponderating action of acids and alkalies, afford a striking corroborative test in favor of the truthfulness (rather than an objection and argument against the truthfulness) of the electrical theory of colors. Precisely similar changes of color of vegetable infusions from blue to red are producible by immersing the two points of wires constituting the circuit of a galvanic battery. The negative battery wire induces an electro-polarization of the freely movable atoms of the solution similar to that induced by the addition of the excess of atoms of oxygen, constituting the efficient negative element of the acids; whilst the positive end of the wire induces an electro-polarization of the atoms of the same solution similar to that induced by an excess of atoms of potassium, of calcium, and other bases of various classes of alkaline salts.

A simple electric spark disturbs the electro-polarized condi tion of groupings of the bright vermilion, with which playing-cards are imprinted, and changes the red tint to a black, or negation of colors; and Mr. Bain actually has recourse to the process of *electro-dyeing* dark blue or purple spots on prepared paper, as the most effective mode of marking telegraphic records through the medium of electro-dynamic action. Electric agency is thus actually employed to accomplish the process of dyeing at the remote distance of several hundred miles from the exciting battery. The office of an "Electro-Chemical Telegraph," is therefore, practically, a species of dye-house, operated by electro-dynamic agency.

As the changes of colors are producible by changes of electro-polarization, it may not, perhaps, be an unscientific anticipation to suppose that galvanic batteries, at some future day, may be introduced into the dyehouse of the practical artist, to accomplish some of the interesting processes of this ornamental branch of the useful arts.

It is familiarly known that by the process of dyeing a *white* silk ribbon to a black or negative color, the character of the electrical reaction developed by friction thereof becomes reversed. The white end of the same piece of ribbon exhibits a "positive" reaction, and the dyed black end the opposite "negative" reaction.

This simple experiment serves to illustrate the fact, that the circumstance of color is due to positive electro-polarized conditions of bodies; for if the ends of a piece of *white* ribbon, which are reciprocally urged asunder after being drawn between the thumb and finger, are found to become urged toward each other on repeating the same process after one end has been dyed *black*, we can form no other conclusion from this fact, than that this change of color is an indication of an absolute change of the electro-dynamic conditions of the groupings of the atoms of the silk.

Even in the dark, differences of colors may be detected by the mechanical action and reaction propagated between bodies, as two pieces of black and white silk require considerable force to separate them after mechanical action of friction has been applied to them; whereas two pieces of the *same* color require actual force to bring them into close contact. Shades of colors exhibit intermediate shades of difference in propagating this electro-dynamic action.

Successive additions of highly positive alkalies and of highly negative acids are systematically employed by the practical dyer to produce the electro-polarizations of the atoms of various vegetable organic formations of dyestuffs, for the purpose of varying shades of colors.

If changes of colors be thus due to electro-polarizations of atoms, then all chemical tests based on the standard of changes of colors, must be essentially electrical tests. The electrical theory of colors, for this reason, becomes more firmly established by showing that chemical action itself is a collateral branch of the same science of electro-dynamics.

The art of the Dyer is founded on a practical knowledge of the different electro-dynamic relationships of the groupings of elementary atoms, from extremely negative oxygen, to extremely positive potassium. These different kinds of atoms he selects, and brings into contact with each other; that is, within the sphere of action of each other's reciprocal electro-polarized forces, instead of the distinct forces denominated *chemical.* Indeed, the empirical employment of the numerous classes of crystallized salts, used by dyers and calico printers, appears to be a conclusive proof of the fact of changes of electro-polarization of the component atoms of the drugs and dyestuffs induced by commingling atoms of inorganic and organic formations, artfully brought into contact with each other within the porous structure of the tissues dyed thereby.

To show the wonderful extent to which this electro-polarizing influence may be propagated throughout a grouping of a mass of atoms, it may be stated that so minute a portion of Iodine as only $\frac{1}{450000}$th part of a liquid solution of starch, with which it may be mixed, is found to affect the electro-polarization of the whole mass. It is thereby caused to propagate the electro-dynamic action of the sun, incident thereon, with the peculiarly modified degree of intensity, which produces a sensation or perception of a *blue* color.

The presence of a greater or less quantity of an excess of atoms of oxygen, chlorine, &c., in various acid compounds, determines the electro-polarizations of organic grouping of various vegetable and animal dyestuffs, as is familiarly known to every practical dyer and bleacher.

In the *fading of colors*, we are afforded with an incontestable evidence of the electro-dynamic powers of the very sunlight which developes colors. The exceeding sensitiveness of certain groupings of atoms to mechanical action of light, is exhibited by a solution of the chloride of silver diluted a millionfold, to which a cloudiness is thereby imparted.

These, and numerous other facts, which our limits will not admit of pursuing farther in detail, demonstrate that the electro-polarizations of atoms, sustaining their mechanical groupings into various organic and inorganic formations, determine the propagation of the electro-dynamic action, by different degrees of intensity of undulatory vibrations, to the electroscopic nerves of the eyes of sentient beings.

The preceding investigations exhibit the three distinctly classified kinds of rays, denominated "Chemical rays," and "rays of Heat," and of "Light," as being simply differently modified forms of the propagation of mechanical action through the medium of electric matter.

The following experiments demonstrate that a regular scale of increase of the intensity of electro-dynamic action on the electroscopic nerves of the eye induces a perception of the various hues of prismatic colors, from the violet to the green.

That the perception of the prismatic colors is produced by a regular gradation of intensity of propagation of electro-dynamic action, appears to be illustrated by a very simple experiment devised by Mr. Singer. "Insert the two points of conducting wires, constituting the circuit of a Leyden jar, about 1½ inches asunder, beneath the surface of a damp pine board, in the direction of the grain of the wood, one of the points being sunk to a greater depth than the other. The spark in penetrating obliquely produces a regularly diminished action on the nerves of the eye, being most intense where most superficial, and less intense where screened by a thicker body of the woody fibre."

"The regularly decreased scale of gradation of the electro-dynamic action on the nerves of the eye is recognizable as a perception of a graduated scale of prismatic colors, constituting a beautiful experiment."

It appears by a communication published by an eminent investigator of the science of Light, Professor Draper, of the University of New-York, (Silliman's Journal, March 1848,) that the prismatic hues *do not appear to differ in any respect*, however compared, whether they originate from a piece of intensely ignited anthracite coal, or the beams of sunlight. The account given by him of the waning intensity of the electro-dynamic action, as the coal burned less brightly, is graphically descriptive of the gradual decrease of the electro-dynamic action on the electroscopic nerves of the eye. "One ray after another disappeared in due succession. First the violet became extinct, then the indigo, then the blue, then the green, until finally the red, with an ash gray light occupying the place of the yellow, was alone visible, and presently this went out."

The triangular shape of the prism, used for developing the rainbow hues of colors, is precisely adapted to deflect from a direct line the propagation of mechanical action through the medium of electric matter in the specific form of light, as denoted by the term ***Refraction.*** By effecting a gradual diminution in the degree of intensity of the electro-dynamic action propagated to the electroscopic retina of the eye, the perception of a chromatic scale of colors appears to be a consequence theoretically to be anticipated.

The electroscopic nerves of the eye do not take cognizance of electro-dynamic action propagated from a heated body, until the intensity reaches the degree indicated by about 700° of Fahrenheit's scale, which is recognized by the popular term of *incandescence;* whilst the nerves of feeling are sensibly affected by slight changes of temperature. The propagation of electro-dynamic action from the molecular vibrations of solid matter exerts a less intense excitation of the electroscopic nerves of the eye than is exerted by the propagation of resilient solar action, by "reflection," or by "refraction," from the surfaces of bodies. The excitation of a piece of incandescent iron appears to have attained the last degree of the red bordering on the violet, before the action becomes propagated through the air, or through transparent bodies, to the nerves of the eye. For this reason incandescent bodies do not appear to pass through the several changes of the prismatic colors which characterize different grades of intensity of refracted or reflected light.

In the disruptive discharge of electricity through the air, through void space, and through different kinds of conducting substances, there is propagated to the electroscopic nerves of the eye various intensities of electro-dynamic action, producing perceptions of various colors.

The color of electrical light varies greatly, even between the same metallic conductors, exhibiting transitions from the most brilliant white to the most delicate violet, according to the distance through which the electricity is transmitted, and according to the resistance of the medium which it is compelled to traverse. In exceedingly rarefied air, the color of the spark is *green;* in denser air it acquires a *blue* tint, and passes to a *violet* and *purple*, in proportion as the condensation of the air is increased. Transmitted through various other gases, the color is found to vary according to their density. In carbonic acid gas the spark is *white* and vivid; in hydrogen gas it is faintly *red*. In the vacuous space beneath the bell-glass of an air-pump, a current of electricity presents the appearance of a lambent flame of various colors; and, in some peculiarly modified experiments, all the colors of the rainbow are simultaneously presented to view. These colors also occur in the coruscations of the aurora borealis.

The experiments made by the London Electrical Society show that the distinct prismatic colors resulting from the deflagration of various metals in the intense flame of an electrical current "seemed sufficient to indicate the peculiar metal consumed." For if the metallic substances, reduced to thin leaves, be subjected to the action of a current of galvanic electricity, they become electro-polarized, and then recoil to their natural static condition, like fuel, rendering manifest the phenomena of *various hues of colors* according to the kind of metal consumed in the experiment. Silver leaf has been thus found to emit an *emerald green* light; lead a *purple*, zinc a dazzling *white* light, &c.

By the discovery of Nobili, in 1826, of a very remarkable class of facts illustrative of the powers of electrical currents to produce a perfect chromatic scale, or gradation of colors, a new application of science to the useful arts has been effected in imparting brilliant colors to metals, which has been termed, "metallo-chromy."* A solution of acetate of lead is poured into the vessel, in which is arranged a plate of platinum, with a pointed wire of the same metal terminated $\frac{1}{24}$th of an inch above it. The solution is made to cover the plate, and to rise two or three lines higher than the point of the wire. The plate and the point are now brought into communication, the former with the positive, and the latter with the negative pole of a galvanic apparatus. At the moment when the galvanic circuit is closed, a series of rings (similar to those formed at the centre of the Newtonian lenses) is to be seen on the surface of the plate, precisely under the point.

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* Taylor's Scientific Memoirs.

The productions obtained by Nobili, by this process, consisted of several plates of colored metal of beautifully vivid tints. M. Nobili states, that "the effect produced by these tints, when arranged in order, baffles description. It bears a resemblance to that produced on the ear by a scale of semitones executed by a perfect voice. In all persons to whom it has been exhibited, it has excited but one feeling of delight. So gradual, indeed, is the transition from one tint to another, and such the harmony with which they are blended, that if the eye be accidentally turned away, it reverts in a moment, as if moved by an irresistible desire to gaze still longer on the display." He continues, "this statement is no exaggeration. It is but the mere fact, in respect to which a language much more glowing would be perfectly consistent with truth; so overpowering is the charm which, if I may use the expression, pervades the scale of our colored plates."

The relationship between the external electro-dynamic action of different colors, developed at sensible distances by the groupings of atoms into masses, and the internal electro-dynamic action among the constituent atoms at insensible distances, is most impressively illustrated in the practical manipulations of the smith at his forge, in tempering steel. The scrutinizing eye of the workman is steadfastly fixed on the flickering rainbow tints, which play, like an aurora borealis, over the surface of the gradually cooling piece of steel, and stealthily change, first from a cherry red to a pale yellow hue, then to brown, then to purple, then to bright blue, and finally to a dark blue.

So perfectly do the *changes of color* indicate the exact degrees of the molecular or electro-dynamic forces excited between the atoms of steel, from the hardest inflexible file and chisel, to the most elastic watch spring, that the following description of the *changes of color in tempering steel* has been published for the instruction of practical workmen.

The knife-blade, chisel, or other steel article to be tempered, is first excited in the forge-fire to a red heat, and is then carefully watched until the chameleon-like surface of the metal becomes suffused with any one of the colors named in the following table. At the instant the color adapted to produce the desired temperature appears, the steel is plunged into water, oil, or other cold fluid, as if for the purpose of fixing the groupings of atoms in the particular electro-polarized conditions which may at that moment prevail among the atoms.

Table of Changes of Colors for tempering Steel.

Fah.		
430°	Slight yellow,	Produce the razor and lancet temper.
450	Pale straw,	
470	Yellow,	" " Penknife "
490	Brown,	
510	Brown and purple spots,	" " Pocket knife "
530	Purple,	" " Table knife "
550	Bright blue,	" " Scissor "
560	Blue,	" " Spring "
600	Blackish blue,	

To obviate this careful inspection it is now common to heat the steel in baths of melted alloys of metals, which fuse at the several temperatures specified in the above table. From these the pieces of steel are withdrawn, and plunged in cold water, or other cold liquids.

Thus it appears that even in the workshop of the practical artist, the philosophy of thermo-electric excitation, and the waning of it in the most valuable implements made of steel, is fully understood experimentally, even to the specific degrees of the scale of the thermometer; which thus not only serves, as its name implies, for the purpose of *measuring* the changing degrees of *heat*, but also the corresponding changing degrees of colors; and, what is still more remarkable, the intensity of the electro-static condition of the natural force which holds fast together the component particles of the steel are thus ascertainable by noticing the colors of the surfaces. The electro-dynamic action which sustains the internal electro-polarization of the molecules, and which constitutes the molecular forces, is demonstrated by this experiment to govern the degree of intensity of the external propagation of the electro-dynamic action of the sun incident thereon, to the optic nerves of sentient beings, recognizable as perceptions of colors.

Pictures produced by Sunlight on Silvered Plates, by the Daguerreotype Process.

The production of pictures by sunlight constitutes the most surprising discovery of the present age. It has given birth to the new science of Photography, which has become also a branch of business in nearly every village, and has nearly superseded the art of the limner in miniature painting.

Among the substances that have been long known to be most delicately sensitive to peculiar excitation by the inductive action accompanying the development of the phenomenon of light, are the combinations of nitrogen and chlorine with several of the metals, which have received the names of *nitrates* and *chlorides* of the respective metals with which they may be grouped. The remarkable action of solar light on a mixture of chlorine and hydrogen gases has been referred to at page 362. The slight mechanical action occasioned by the touch of a feather, as has been recapitulated, is sufficient to determine a change of polarization among the groupings of atoms of nitrogen and silver in the constrained static conditions of fulminating powders. The "Chemical" action of light, producing the result of the change of the nitrate of silver into *black* crystals of oxide of silver, has been referred simply to *Mechanical* action propagated through the medium of electric matter. But by the Daguerreotype process, there is no change of *color* of any of the materials employed; it is purely a case of the development of electro-mechanical attraction between the surface of a sensitively prepared and excited silver plate, and globules of mercury reduced to the state of vapor in the air adjacent thereto, (page 361.)

The facility with which a colorless solution of the nitrate of silver becomes an indelible ink on exposure to light, has been long rendered practicably available by careful housewives in marking linen. The same salt of silver has also been familiarly employed for dyeing the silvery white hairs on the heads of persons whose modesty induces the avoidance of an ostentatious display of "the crown of glory of old age."

These facts of the change of colorless preparations of nitrate of silver to *black* being known, it became a favorite subject of speculation to turn this property to a useful account by means of introducing sheets of paper, moistened with the solution, behind the lens of the solar microscope and of the *camera obscura.** It was calculated that if the surface of a sheet of white paper, dipped in a colorless solution of the nitrate of silver, could be subjected to the same influences of lights and shades, as were exhibited on the surface of the interior side of the dark box in front of the lens of the camera obscura, that the nitrate of silver would become changed to more or less intense shades of black, which would exhibit a faithful delineation of the lights and shades of the objects presented before the lens. From experiments of this kind originated the first conception of producing pictures by the agency of light.

The earliest recorded attempts in this branch of science were made by Wedgwood and Davy; an account of which was published in the year 1802. Neither of these experimenters were successful in producing distinct pictures by means of placing their prepared paper within a camera obscura. The latter succeeded in doing so by means of the lights and shadows produced by a solar microscope. But as the experimenters were ignorant of the means of preventing the further action of the light on their prepared paper, their pictures became suffused with one common, overspreading, black hue, in the very act of exhibiting them by exposure to daylight.

Thus baffled in these early attempts, no other experimenters appear to have entered the field until the year 1814, when Niepce in France, revived attention to this subject.

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* These Latin words signify "a *dark chamber*," derived from the use of a convex lens inserted in the shutter of a *dark room*, whereby the images or pictures of all objects in front of the lens were exhibited on the opposite wall of the chamber. A small portable box, constructed on the same principle, is now familiarly used for the exhibition of this experiment.

It appears from the following account of the progress of the discoveries in photographic science contained in a recent number of the Revue des deux Mondes, that Niepce commenced experimenting upon the newly-discovered process of Lithography; and after various unsuccessful attempts to employ polished metals coated with lithographic varnish, as a substitute for stone, "he conceived the idea of obtaining on metallic plates the representations of exterior objects by the action of luminous rays."

He covered plates of polished pewter and tin with layers of dark-colored substances, which were known to possess the property of becoming bleached white by exposure to the light, such as asphalte, and certain resinous substances properly prepared. Having varnished the backs of engravings to render them more pervious to the light, he placed them over the prepared plates, and exposed them to the light. The black parts of the engravings arrested the luminous rays, whilst the transparent white parts, where there were no lines of the printing ink deposited, allowed the light to pass freely to bleach the asphalte spread upon the plate. He thus succeeded in obtaining a copy of the drawing, the lights and shades being represented by the bleached and black parts of the asphalte.

But these rude copies required ten hours' exposure to the light to bleach the materials employed, and possessed so little merit, that he did not rest satisfied with them; and he continued his attempts at improvement, encouraged by the fact of having resolved the possibility of producing change of color, and the lights and shades of pictures, *by the agency of light.* It was not, however, until about the year 1826, that Niepce finally succeeded in producing pictures, in which the lights and shadows were represented, and unchangeably preserved, whilst afterwards exposed to the further action of light. This last important result he accomplished by washing speedily the preparation of the salt of silver with a solution of neutralizing salts.

It happened one day that a spoon, left on a prepared plate of *iodized silver*, produced a permanent shade upon the plate under it, which was not then acted upon afterwards by the influence of the light. This lesson was not lost.

The discovery of the mode of arresting the further action of the light on the plate by washing it in a solution of neutral salts, was a decisive step in the advancement of the science of photography, and "in resolving a problem, which had cost twenty years of assiduous labor."

"But it was not reserved for the inventor to enjoy the final triumph, on which he had staked the hopes of his success in life. Niepce, then at the age of 63, died, poor and unknown, in the year 1833, at Chalons, in France. The author of the most interesting discovery of our age passed away without fame, unnoticed by his fellow-citizens, with the cheerless reflection that he had lost twenty years of his laborious career, dissipated his patrimony, and impaired the future prospects of his family, in the pursuit of a chimera."

Daguerre, after having seen, in the shop of an optician in Paris, some of the specimens of the pictures executed by Niepce, formed a connection with him for the purpose of making further improvements. After being possessed of the knowledge of the plans and processes of Niepce, Daguerre pursued a course of experiments with various kinds of substances, which exhibited changes of color by exposure to light. "He used, instead of the asphalte, the resin which is obtained by distilling the essence of lavender,— a material which has a certain luminous sensibility. But, instead of washing the plate in an essential oil, he exposed it to the action of the vapor furnished by this essence at the ordinary temperature." This vapor was *attracted by the parts of the plate excited by the light*, and condensed on the surface of the resinous coating, in a dewy deposit. The lights in the picture of the objects produced in the camera obscura were represented by the white bleached parts of the resin,—the shades, by the resin which had been dissolved by the condensed vapor of the essential oil, so as to form a transparent bed on the surface of the metal. The contrast of lights and shades between the whitened parts of the bleached resin, and the dark transparent parts on the plate, served to produce a representation of objects, resembling a drawing.

Subsequently Daguerre continued his experiments with plates of silver, and of copper with silvered surfaces, to reduce the expense, the surfaces being rendered sensitive by the application of nitric acid and chlorine, which converted them into nitrate or chloride of silver. Instead of evaporating the essential oils, which he had used for the previous resinous preparations, it occurred to him to employ the vapor of boiling mercury, to become attracted by the surface of the silver plate whilst excited by the influence of the light, directed upon it by the lens in the camera obscura. This final experiment rewarded his labors with a decided success, which will for ever connect the name of Daguerre with this new and wonderful branch of science.

He received, in 1839, from the French Government, the grant of a pension for life of only 6000 francs a year, for divulging the particulars of the process, and the right of the use of it by the public; a sum which has been yearly realized by many who have subsequently practised the art for gain.

In justice to the memory of Niepce, a similar pension of 4000 francs was granted to his son.

Having been able to find no published theory explanatory of the Daguerreotype process, the following explanations are given as suggestions, rather than as established doctrines.

The important improvement made by Daguerre was the process of exposing the prepared plate to the vapor of boiling mercury, the brilliant white globules of which become attracted in greater or less quantity by the specific portions of the sensitive plate, in proportion as they have been more or less strongly excited by the action of the light directed thereon by the lenses. Globules of dewy vapor of the atmosphere on a sultry summer day become similarly deposited on the surface of a glass of cold water. Were some parts of the glass less cold, or rather more excited by heat, than others, there would be a corresponding difference in the quantity of dewy globules of water collected on the different parts.

The following are the principal photographic manipulations constituting the processes for producing miniatures and landscapes from nature, which are denominated—

DAGUERREOTYPE PICTURES.

Although the details into which we have entered in illustration of this subject may not be strictly in accordance with the plan of an elementary treatise, yet the principles of the mechanical action of Light are admirably disclosed thereby.

The process invented by Daguerre is comprised in five distinct operations.

1. In preparing the sheet of copper, plated with silver, by imparting to its surface the most exquisite possible polish, so as to exhibit a *dark* lustrous surface, which is destined to constitute the dark ground for the shades of the picture.

2. In applying to this surface of the polished silver a coating of iodine, or chlorine, to render it excitable by the propagation thereto of electro-dynamic action in the form of Light.

3. In dexterously transferring the sensitively prepared plate, without exposure to light to the focus of a lens arranged at one end of the interior of a dark box, which is designed to produce a picture of the objects, presented before the glass, upon the surface of the plate.

4. The plate, after being excited by the action of the light thus directed upon it, is transferred into another dark box directly over the vapor of mercury, boiling by the heat of a lamp.

The particles of the vapor of the mercury, in their ascent, come in contact with the plate, and become most strongly attracted by the specific portions of its surface, where the lights of the picture were most strongly directed by the lens; and less strongly, or not at all attracted, where the darkest shades of the picture were cast on the plate. Between these two extremes, there is a scope for all the gradations of excitation by the electro-dynamic action of the light; whereby the white globules of the vaporized mercury become deposited, like dew, most abundantly on the portions which have been most intensely excited, thus covering those parts of the plate with a deposit of the white globules of mercury, to represent the strongest white lights of the picture. A less abundant deposit on other parts of the surface of the plate corresponds exactly with the grade of intensity of light directed thereon.

The same attraction of the surfaces of all bodies for vapory molecules floating in the surrounding air takes place on summer evenings, according as their surfaces are more or less excited by solar action during the day. Masses of rocks and of metals retain their excitation, and a *repulsion* instead of *attraction* ensues between the surfaces so excited by *heat*. The difference in this case is ascribable to the opposite electro-polarization induced by solar action on the sensitively prepared surface of the nitrate of silver. But the surfaces of a lock of wool, of a spider's web, or of spires of grass, radiate speedily the heat imparted to them by the sun, and become, (by a few degrees of the thermometer,) colder than the surrounding air. The difference of temperature indicated by the thermometer when this attraction begins to take place between the molecules of vapor, floating in the air, and the surfaces of bodies exposed thereto, has been denominated the DEW POINT.

Supposing the dew-point to be 60° Fahr., and the vapor in the surrounding air to be 70°, it is manifest that if one portion of the surface of a plate of metal be excited to the temperature of 70°, and another portion to the temperature of 50°, that the drops of water will become attracted from the air, and deposited on the colder part of the plate, whilst none at all will become deposited on the warmer part.

The quantity of particles will vary from a most abundant deposit at 50°, by a regular decrease of deposits, to none at all at 70°, precisely as the temperature of the different portions may vary from 50° to 70°.

The quantity of particles of mercury deposited will vary in like manner on the different parts of the Daguerreotype plate, according as the different parts of it may be more or less intensely excited by the electro-dynamic action in the modified form of the *Light* distributed upon it by means of the lens of the camera obscura. As the parts which have received no excitation are the actual shaded parts of the plate, such parts attract none of the particles of the white glittering globules of mercury, and consequently remain of the original dark, lustrous ground of the cleanly polished silver; whilst the parts on which the brightest lights of the objects presented before the lens have been cast, will attract the most of the white globules of mercury, and will thus exhibit the brightest lights of the Daguerreotype picture.

Between these two extremes, all the intermediate lights and shades are distributed with perfect truthfulness, to the precise degree of excitation with which they are severally affected; and thus the unerringly exact representation of the lights and shades are produced which excite the admiration of every beholder.

The effect of the electro-dynamic action, which causes particles of mercury to become attached to the portions of the plate excited by the light incident thereon, may be illustrated by Leichtenberg's experiment of drawing figures of trees, animals, &c., on a cake of wax, with the excited knob of a Leyden jar, and by then sifting powdered sulphur over it. On inverting the plate, the particles will fall off from all parts of the surface of the cake of wax, except the portions excited by the contact of the knob of the jar, where they will be found adhering, presenting yellow colored outlines of the figures drawn upon the cake of wax with the knob of the Leyden jar. By passing over the same cake of wax the knob of another Leyden jar excited by contact with rubber of an electrical machine, and by similarly sifting a powder of red lead, both designs will simultaneously become developed, the one in yellow and the other in red lines.

A similar effect may be produced by drawing with the end of a magnet on a tempered steel plate similar outlines of figures. On sprinkling iron filings over the surface of this steel plate, which represents the process of causing the particles of the vapor of mercury to rise up in contact with the surface of the Daguerreotype plate, excited by the electro-dynamic action in the specific form of light, the particles of iron will be found to adhere to the surface of the steel plate, as the particles of mercury adhere to that of the Daguerreotype plate.

After a sufficient quantity of the white globules of mercury have become deposited on the plate, it is withdrawn, to be subjected to the last, and—

5th operation, requisite for fixing the globules of mercury, and also for neutralizing the further sensitiveness of the plate to the action of light. This is effected by pouring cold water thereon, and by dipping it into a solution of the hypo-sulphite of soda. The fixation of the particles of mercury is effected by pouring a solution of the chloride of gold on the surface of the plate, whilst arranged horizontally on the stand above the blaze of a lamp, where it is allowed to remain until the electro-dynamic action causes the image to become clear and distinct. After this operation, the picture is again washed, and is ready for the frame.

The surface of the silver plate being exquisitely polished, presents a dark lustrous expanse, like that of a calm lake, whose waters, when looked down upon from an eminence, appear black.

On this dark surface of the polished silver, the clustered portions of the globules of quicksilver produce a pure resplendent white color; and this whiteness is shaded off on the other parts of the plate less excited by the rays of light converged upon them, exactly in proportion to the degree of intensity of the photo-electric action, and in perfect truthfulness to nature.

These globules are so very slightly attached to the surface of the plate as to be readily brushed off like dew-drops by a feather, until somewhat more firmly fixed by the chemical action of the solution of the chloride of gold poured over it.

By means of the process to be described for electro-gilding, a very thin coating of gold may be imparted to a Daguerreotype plate, communicating to the surface the appearance of a golden plate, and a rich tone of color to the picture, without depriving it of its distinctness. By M. Fizeau's process to accomplish this result, the plate is immersed in a solution of hypo-sulphite of gold, and a wire from the zinc of a feebly charged battery is brought against one of its edges; whilst a plate of gold, connected with the copper of the battery, is immersed in the solution exactly parallel with the surface of the picture. By carefully watching the exactly proper degree of the deposit of the film of gold, a rich transparent gilding is imparted to the picture.

The *coloring* of Daguerreotype pictures is accomplished by causing the impalpable powders of various pigments to settle lightly on the parts to be tinted, where they become fixed by gently breathing thereon.

By the ingenuity of Mr. Groves, the beautiful pictures produced by the process of Daguerre have been permanently etched on metallic plates, by means of the galvanic battery, in about 30 seconds.

In order to test the fact of the development of chemical action between the prepared Daguerreotype plate and the vapors of iodine and bromine, E. Bequerel states in his treatise on Electricity (vol. vi. page 64), that with an abundant coating of the vapor of iodine, a pretty intense current of electricity was discoverable by means of the deflection of a galvanometer needle, in such a direction that the plate received, or yielded, electricity, according to the thickness of the deposit of vapors of iodine.

" When the chloride of silver is freshly precipitated upon a plate of platinum plunged in water, it was noticed that at the instant the plate was exposed to the rays of the sun, the chloride became darkened, and the needle of the galvanometer (connected by a wire circuit therewith), became deflected several degrees, in a direction indicating the plate to be in a positive electric condition. A plate of silver does not admit of a similar action, since its reaction upon the chlorine, resulting from the decompostion of the chloride, produces a current in a reverse direction."

"The surface of a plate of platinum having been covered with a freshly precipitated coating of chloride of silver, and then exposed to the direct rays of the sun, caused a deflection of the needle of the appended galvanometer of 7° 5'. To demonstrate that this degree of electrical excitation is not due to the thermo-electrical action of the sun, the needle was found to be deflected only 1°, when a very clean plate of platinum was similarly exposed to the sun."

"The chloride of silver at the instant of exposure to the sun was *white*, when the deflection of the needle was found to be - - - - -	7° 5'
After exposure to the sun for one quarter of an hour, the chloride of silver became of a *deep violet* color, when the deflection was - - -	5° 5'
After exposure for an hour, - - -	3° 0'

The *chemical action* of the iodine or chlorine, applied to the surface of the silver daguerreotype plate, and the violent process of mechanical friction applied to polishing its surface to an exquisite lustre, are, doubtlessly, the artificial means employed to reduce the surface of the plate to the same constrained static condition as that to which the retina of the eye is naturally reduced by the organic action controlled by vitality.

Thus, every view of a landscape or of other objects, similarly produces a perfect daguerreotype picture on the sensitive surface of the retina of the eye, which is recognized by the tribunal of intelligence located in the brain, as transient pictures.

The preceding facts, when philosophically reviewed, may serve to demonstrate that there is a very remarkable analogy between the pictures permanently delineated by the excitation of Light on the sensitively-prepared plates placed within the camera, with convex lenses to direct thereon the converging rays, and the pictures transiently delineated by the excitation of Light on the sensitively-created retina of the eye, similarly placed behind a lens in the dark chamber of the skull. The mechanism of the one is planned by the art of man, as it were in imitation of that of the other, planned by the omniscient power of his Creator.

Assuming this theory to be true, the impressions of pictures of distinct objects, and the lights and shades of their outlines,—the very hues of their colors melting into each other by blended gradations, become all resolvable into the more or less intense inductive excitation of the expanded net-work of nerves constituting the sensitive retina, which is suspended behind the lens of the eye, like the sensitively-prepared plate in the dark box behind a glass lens.

It may be permitted to us to pause here, for a moment, to consider the mysterious powers of vitality and intelligence, which are not only capable of taking a species of daguerreotype copy of every landscape, and of other objects upon which the natural lens of the eye is turned to gaze, but of preserving these copies, clear, defined, and distinct, in the storehouse of the memory, as in the gallery of a photographic artist; to which, at pleasure, the immaterial essence of the god-like mind recurs, to examine and re-examine faces and forms that may have ceased to exist except in these sunlight pictures in the gallery of memory.

That there is an action on the retina producing pictures similar to those on the sensitively-prepared plates, is confirmed by the fact, that the impressions vividly excited on the former remain distinctly impressed thereon during an appreciable period of time. On closing the eyes suddenly, after viewing the bright light of a blaze of gas, or of a solar lamp, the outlines of the flame appear to remain for a time distinctly portrayed; and the rapid whirling of a fire-brand leaves the impression of a perfect circle of fire, instead of a continuous movement of a single object about a centre.

It is owing to this abiding impression, that we find our powers of vision to fail of receiving impressions from objects presented to view, and withdrawn, oftener than 8 or 10 times in one second; for the photo-electric excitation produced by the presence of one object before the lens of the eye must have time to subside, before a fresh excitation can be induced; otherwise the successive excitations become blended confusedly together, as would be the case under similar circumstances on a prepared daguerreotype plate.

This fact is illustrated familiarly by moving rapidly back and forth before the eye the little figures of bright blue and red colors, which constitutes one of the many interesting experiments of the optical delusions producible by modifications of the propagation to the electroscopic nerves of the eye, of the electro-dynamic action of Light.

These principles of the propagation of impulses of mechanical force from the electro-dynamic action of the sun in the form of the mechanical action producing the phenomenon of LIGHT, admit of further very simple and beautiful illustrations, by means of employing direct electric-excitation, as is manifested in Mr. Karsten's experiments of passing an electric discharge through a coin placed upon a plate of glass. He states that the electro-mechanical action, thus induced, will attract the vapor of mercury and of iodine, and even the vapor of the breath, so as to render the superscription of the coin distinctly visible on the surface of the glass.

Mr. Hunt states that when a piece of copper coin is gently heated, or *thermo-electrically* excited, as it may be termed, and placed upon a cold plate of polished silver, and then speedily removed, by then breathing on the plate, or by exposing it to the vapor of mercury, the figure of the coin becomes " beautifully visible."

The various figures and fanciful representations of trees, animals, &c., which appear portrayed in the fairy-like frost-work of the window panes on wintry mornings, are doubtlessly the regular effects of electro-dynamic impulses propagated in the form of photo-electric, or thermo-electric action.

The preceding facts of the attraction and condensation of particles of vapor from the air exhibit such a striking analogy to the deposition of DEW, as to carry conviction to the mind of the identity of the electro-dynamic cause of this phenomenon, as has been detailed at page 292.

The process of producing pictures by the agency of light, may be denominated the *electro-mechanical* process, as it is founded on the attraction of the surface of the prepared plate for particles of mercury, &c. Whereas the original process of producing pictures by the changing of the color of the salts of silver, was founded on *electro-chemical* principles of the corpuscular changes among the groupings of atoms of these salts.

About the time that Daguerre was engaged in pursuing his experiments in France, Mr. Talbot, in England, was similarly engaged in perfecting the original electro-chemical plan of producing pictures on sensitive, prepared paper, instead of metallic plates.

The discovery made by Mr. Talbot is described by him as having originated accidentally, whilst he was trying some experiments on the relative sensitiveness of several kinds of prepared papers, which he exposed to the light in a camera obscura. He threw aside some of the papers in a dark room, as exhibiting no visible impressions. "After some time, these were again examined; and, strange to say, by a process of natural magic, pictures of the objects to which the camera had been pointed, were found to be formed on them in the dark."

His process has been patented in England for preparing an extremely sensitive paper, for the purpose of taking portraits, landscapes, views, &c., by means of a camera obscura; which process is essentially as follows:—A sheet of fine letter paper is brushed over with a solution of 500 grains of the iodide of potassium in a pint of water, and dried between folds of blotting-paper. A solution of nitrate of silver in the proportion of 170 grains, to 1 oz. of water, and 1½ drams of pure acetic acid, is carefully spread over its surface. After the paper has been dried, and again dipped in the solution of the iodide, it is to be gently washed with distilled water, and then dried. An uniform coat of pale yellow iodide of silver is thus spread over the paper.

To give this prepared paper its most sensitive powers of receiving impressions from light, it must be rapidly brushed over with equal parts of the acid solution of the nitrate of silver and a cold saturated solution of gallic acid. It must then be immersed for a moment in distilled water, and drained on blotting-paper. In this state it is remarkably sensitive, and, when nearly dry, may be used in the camera. A beautiful picture is produced on it, often in a few seconds, although invisible to the experimenter until he "brings it out" by again washing it with the mixed solution of silver and gallic acid, keeping the paper warm by placing it in a dish over boiling water.

The picture thus produced may be *fixed*, by washing it first with water, and then with a solution of 100 grains of bromide of potassium in 10 ounces of water. This process, from the beauty of the pictures, is termed the "calotype" process: a word derived from the Greek, signifying "*beautiful*."

By means of this invention, the traveller is enabled to carry with him the prepared paper and the apparatus, for taking perfectly exact sketches from nature of the landscape views and objects which would require much labor and art to perfect with the pencil. At no distant day this apparatus may become a common appendage to the luggage of the tourist, who may thus enrich his portfolio with interesting sketches, from nature, of the places he may visit.

It has been stated that Becquerel, in France, has recently succeeded in transferring to a Daguerreotype plate the vivid colors of the prismatic rainbow hues! The colors of the landscape views have also been to some degree successfully transferred to a prepared Daguerreotype plate.

The prismatic tints thus producible on the metal are fugitive, no method having yet been discovered to fix them permanently. With the steady progress of discoveries in this interesting branch of science, there is reason to hope that even this final triumph may be accomplished.

The following Table exhibits the variegated colors producible by exposing a piece of paper freshly prepared with a coating of the chloride of silver to the unequal electro-dynamic action propagated through a prism.

Table of Changes of Colors producible by Action of Light.

Where the several prismatic Colors are directed upon the Prepared Paper.		Colors produced on a surface of Paper coated with the Chloride of Silver.
The Red	produces	None.
Orange	"	Faint Brick-Red.
Orange-Yellow	"	Brick-Red.
Yellow	"	Red, passing into Green.
Yellowish-Green	"	Dull Bottle-Green.
Green	"	Dull Bottle-Green passing into Bluish.
Bluish-Green	"	Sombre Blue.
Blue	"	Black, passing into Metallic Yellow.
[illegible]	"	Black.
[illegible] Violet (Lavender)	"	Violet, or Purplish Black.

A piece of prepared paper, after being blackened by violet light, becomes *bleached* or *whitened* by exposure to the red prismatic ray; and Sir John Herschel found that when a violet and red ray were allowed to fall simultaneously on a piece of paper coated, as above stated, with chloride of silver, they neutralize each other's action. This result has been attributed by him to counteracting undulations, agreeably to his undulatory theory.

By the electric theory, this neutralized condition we suppose to be attributable to opposite electro-polarizations of the surface atoms, and to an opposite counteracting action like that produced on a plate of steel by means of the opposite poles of two magnets tied together side by side. When the figures of birds, animals, &c., are traced slowly by a *single* magnet over a sheet of steel, an excitation of electro-dynamic force becomes developed along the lines drawn by the magnet on the surface of the steel; and if fine iron filings be sprinkled against the surface of the plate, the figures traced thereon become distinctly developed by the adhesion of the iron filings.

When two combined opposite poles are used, they represent the neutralized forces of the static needle (fig. 29), and the corresponding neutralized effect.

There is induced among various kinds of elementary atoms by the electro-dynamic action of light, a most remarkable excitation, which causes such atoms to become *polarized*, like magnetic needles, each having its appropriate reciprocally attracting or repelling pole, and each atom being acted upon by impulses of electro-motive forces of attraction and repulsion. It is this specific state of permanent polarization of the atoms or molecules, which determines the permanency of the colors of bodies.

In all the operations of nature taking place around us, the ornamental phenomena of variously diversified colors, and of beautifully symmetrical forms, are secondary results, and incidental to some more important ultimate design of utility than that of simply gratifying the sense of sight of intelligent beings. The fact of the intimate connection of the various colors of bodies with their various electrical conditions, which we have been engaged in describing, teaches us that the perception of the colors of tempered steel, of the rainbow, and of the variegated hues of flowers, are the probable results of a graduated intensity of excitation, essential to the grouping of the atoms of all bodies into the organic and inorganic formations, which have been previously described.

The glorious tints of the rainbow appear kindled up amid the dark clouds as a cheering beacon of hope to desponding man, amid the gloom and imminent threatenings of the impending storm. Yet we know that this phenomenon is the result of general laws, which are subservient to more important purposes than that of courting the transient gaze of human beings, by displays of beautiful colors of glowing purple, violet, and gold, reflected from the falling rain-drops, or from the fringes of the curtains of the overhanging clouds, excited by the setting sun in the evening sky. We may similarly regard the beautiful array of resplendent colors of the variegated flowers, which are tastefully sprinkled over the surface of the earth. The green expanse of the solitary prairies of the west, spread out from horizon to horizon, are covered with gorgeously-colored petals and expanded leaves, which are primarily designed to receive excitation from the electro-dynamic action of the sun. They are favorably colored for receiving more or less of the exciting solar action, like the changing colors of the fur of certain animals, which occupy the wintry polar regions of the earth. And thus the light developed by the myriads of nebulous stars, which are sprinkled over the dark blue canopy of heaven with the profusion of glittering dust, may be incidentally useful in cheering the pathway of benighted man, and may excite the sublimest ideas in the mind of the contemplative observer; yet we cannot believe that these incidental advantages can be the main design for which these orbs of light are suspended like feeble lamps in the sky.

And thus, by reasoning from analogy, we are prepared to believe that the phenomena of light and of colors are indicative of useful and important operations of a general electro-dynamic agency, which serves to maintain the fixed and harmonious order of arrangement of the component atoms of all lifeless bodies whilst at rest, and their equally fixed and harmonious courses whilst in motion.

Intelligent sentient beings on this earth are endowed with natural electroscopic organizations, every healthful function of which is capable of receiving and propagating in variously directed forms the electro-dynamic action of the sun to produce pleasurable sensations, as if with a studied design of beneficently augmenting the greatest happiness of the greatest number. These considerations serve to impress on every reflecting mind an enthusiastic admiration of the sublime benevolence, as well as of the exquisite skill, displayed in combining the beautiful with the useful developments of the workings of the natural motive-power, which operates the minutest and the vastest mechanisms of the universe.

MACHINES OPERATED BY ELECTRO-MOTIVE POWER.

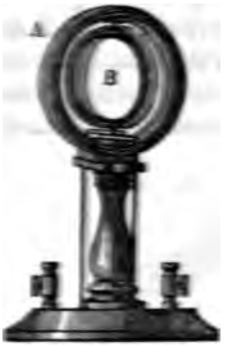
Revolving Movements of Machines produced by the Reciprocal Action of Electric Currents.

The principles of the reciprocal action between bodies serving to propagate electric and magnetic currents, which have been shown to be identical (pages 235, fig. 32, and 240, fig. 36), admit of being very impressively illustrated by numerous kinds of machines, which ingenious men have invented.

It was early anticipated by Savary, Biot, and Wollaston, that the equatorial direction of the electro-dynamic action about magnetic bodies, would produce continuous revolving movements about their axes. Faraday first succeeded in verifying these theoretical anticipations. An instance of the revolving movement of a wire frame by solar excitation, has already been described at page 468, fig. 117. The continuous revolving movement, in this instance, was shown to be the result of the successive reversals of the directions of the currents by the turning of the opposite ends of the wire frame in the focus of the concentrated solar rays, or blaze of a lamp. In all the machines which we shall now proceed to describe, the artificial mechanism of the current changer (fig. 63, page 298) is employed.

The two floating rings of De la Rive (fig. 31, page 223), become turned about so as always to present towards each other those particular sides about which the currents circulate in similar directions.

Fig. X.



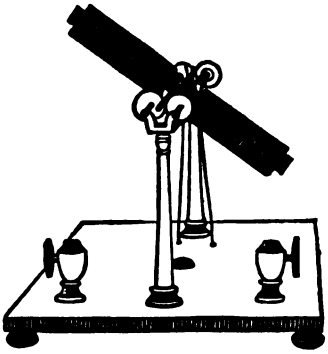
The same result may be more strikingly demonstrated by means of the apparatus exhibited in the annexed figure: where two circular wire coils, or rings, are represented by A and B, which are so arranged on the same common vertical axis, as to allow the smaller one to revolve within the larger one. The connecting cups on the stand transmit the current from a galvanic battery, through the circuit of both rings successively.

If the current be caused to ascend first on the left side of the exterior ring, A, and to descend in its circuit on the right hand side: and if the interior ring, B, be adjusted at right angles to A, with the current descending on the side towards the spectator, this side will be attracted by the right side of A and repelled by the left side. The farther side of B will be similarly attracted by the left side of A, and repelled by the right side, in conformity to the principle already established, that bodies are reciprocally urged to move toward each other, whereon electric currents move in similar directions: and *vice versâ*. Thus the inner ring is urged to swing around on its axis, within the outer ring, until the approximated parts of the two rings serve to propagate the currents in similar directions.

The directions of the currents are now suddenly reversed about the inner ring by the pole-changer. The wire coil is urged again to move, and to make another half revolution; so that the respective currents may regain their conformable relative directions. This result is constantly effected by the apparatus of the self-acting current-changer. The momentum imparted to the mass of the wire coil carries forward with it the parts of the current-changer, which serve to alternate the changes of the directions of the currents; so that although the current in the coil may be for an instant interrupted whilst the wire springs are passing over the interval of space dividing them, yet its immediate restoration is effected by the contact with the approaching semicylinder in a reversed direction.

There is an important lesson taught us by the preceding experiment of these revolving electro-dynamic rings. The mere circulation of electrical currents about the circumference of conducting bodies—it matters not whether they be constituted of aggregations of material atoms in the shape of rings, or of globes, cubes, or other determinate forms—will cause them in the first place to become turned about on their respective axes, so as to bring these currents into similar conformable directions; and in the next place they become moved always toward each other after this result is effected.

Fig. 138.



If a coil of conducting wire be mounted on a stand, like a dipping needle, and the axis be very freely movable on friction rollers, the terrestrial electric currents, feeble as they are, will react on this coil, and bring down one end to dip like a dipping needle, as represented in the figure. The intensity of the action becomes very much increased by inserting a small bar of iron within the coil, which instantaneously becomes a powerful magnet, and augments the action.

The momentum of the descending end will carry it past the regular line of dip of the dipping needle, to a vertical position. If the arrangement of a current-changer be connected with the axis of this coil, so as to reverse the direction of the current at this moment, the polarity will in consequence be reversed, and the lower end of the coil will be urged forward until the elevated pole becomes swung over in the same manner as the opposite pole previously was. The current-changer at this instant again reverses the direction of the current about the coil, and consequently its polarity becomes again reversed, thus producing a continuous revolving movement of the coil, simply by the action and reaction between an artificially-directed galvanic current, and the natural electric currents directed from east to west about the earth's surface.

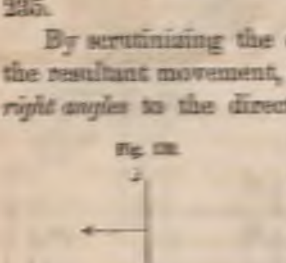
In this case the electro-dynamic action of the sun, indirectly developed through the medium of the recoiling zinc of the galvanic battery, is brought to react on the terrestrial electric currents directly induced by the same exciting cause, thus exhibiting a similar effect to that produced by the revolving frame described at page 488, fig. 117.

The preceding experiments are sufficient to show the machine-like movements resulting from the reciprocal action and reaction between bodies serving to propagate electro-dynamic action in parallel coinciding, and in dissimilar directions.

The next illustration of a revolving movement will be taken from the action of one current at right angles to another, as represented by No. 3 and 7, of the Electro-dynamic Key, page 235.

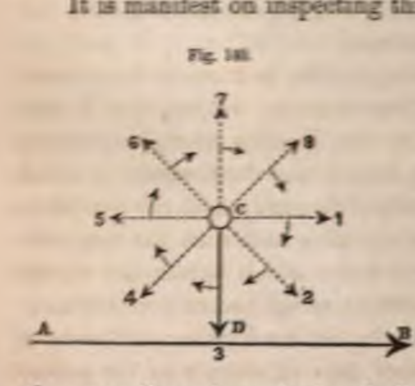
By scrutinizing the direction of the lateral arrow denoting the resultant movement, it will be noticed that it takes place at *right angles* to the direction of the current 3, and in opposite direction of the current A B, as represented in the figure. The movement is the reverse of that of the action as propagated from A B. The intermediate transverse wires, 2, 4, 6 and 8, are similarly urged in rectangular directions, as denoted by figure 140.

Fig. 139.



It is manifest on inspecting this figure, that a wire suspended at C, and serving to propagate a current in each one of the 8 several different directions from the central pivot, must become urged continuously to revolve about the centre like the hand of a watch about the dial-plate.

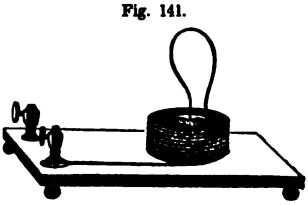
Fig. 140.



Various contrivances have been resorted to for the purpose of practically verifying the preceding theoretical calculations of the revolving movements of bodies, producible by the reciprocal action of electric currents terminated on one side of an extended one. Mercury, as being both a good conductor, and readily movable, in obedience to the impulses imparted to it, was first discovered by Davy to be a readily available test of the revolving movement producible.

It is only necessary to fill a watch crystal with mercury, and to place it within a brass cup, the rim of which is amalgamated, and in connection with one of the screws of the base-board, as represented in the cut. This cup is placed in the interior of a helix, one end of the wire composing which is extended so as just to dip into the middle of the cup of mercury, as shown in the figure. The design of this arrangement is to cause the current from a galvanic battery to flow first about the circuit of the coil of wire environing the mercury cup, and after passing beyond its immediate influence on the mercury, by the projecting bend of the wire, to descend to the centre of the mercury in the watch crystal. From thence it radiates in every direction to the rim, and at right angles to the direction of the current moving along the circumference of the environing helix. This arrangement fulfils the condition of the relative movements of terminated currents at right angles to another rectilinear current, as exhibited in figure 140, the circular current about the helix being regarded as made up of numerous sections of short rectilinear currents moving at right angles to the radiating currents from the centre of the mercury.

Fig. 141.

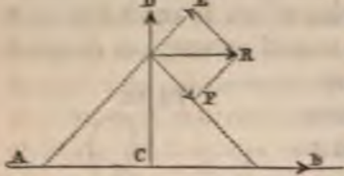


The action and reaction between the portion of the current radiating from the centre of the mercury in the cup toward another portion of the same current moving around the cup in the environing circular coils, causes the fluid mercury, which serves as the pathway of the radiating currents, to revolve like a whirlpool around the point of the wire with such extreme velocity as to produce a centrifugal force, which causes the surface of the mercury at the centre of the cup to become depressed.

If the point of the wire be dipped a very short distance beneath the surface of the mercury, this subsidence of the surface at the centre serves to interrupt the contact and consequent battery current. The whirling motion of the fluid then ceases, and its original level becomes re-established. The battery circuit being thus again restored, the same whirling becomes renewed, and suspended, successively.

The rectangularly directed impulses developed in this case have been demonstrated by Ampère to be a *resultant* of two combined directions of electro-dynamic impulses, one in the line A E, figure 142, and the other in the line toward F. The former is a repellent action, the latter an attractive action. By the usual rule of calculating a resultant force by the diagonal of a parallelogram, it is shown to be in the intermediate direction R, which is in the same direction as the electro-dynamic action is propagated from A to B, and at right angles to the conducting body C D.

Fig. 142.



When, therefore, in any of these experiments, we behold a body moving in a circular orbit, or rotating on its axis by means of the agency of two electrical currents propagated transversely over their approximated parts, we are taught by the laws of electro-mechanical science to consider this remarkable circular movement as a *resultant action of two combined forces.*

The preceding observations show that this reciprocal action of transversely directed currents is propagated in a tangential direction to the line of movement of the two currents, which may be each considered as the radius of a circle circumscribed around the point of their intersection at crossing each other, if sufficiently prolonged, as exhibited in the Key at page 235.

These considerations also serve to awaken attention to a principle or law of the science of Electro-dynamics which we shall presently have occasion to investigate, showing that all approximated freely movable bodies, having unobstructed space around them, and having electro-dynamic action propagated over them in relatively transverse or crosswise directions, must necessarily become urged to move about each other, as is actually the case in the instances of the revolving movements of the huge orbs of matter in the free space of the heavens.

Revolving Movement of a Conducting Wire about a Magnet.

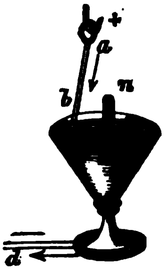
The identity of the reciprocal action and reaction of magnets and spiral coils of conducting wires has been illustrated at page

242, and by the Electro-dynamic Cylinder (figure 36, page 240). It has been shown by the arrangement of a conducting wire suspended from the freely movable joint at W, that the wire W N will become urged to move in the *same* direction as the movements of the hands of a watch about the North or * pole of a magnet, when the electro-dynamic action is propagated *toward* that pole, as denoted by the arrow-heads; and that on propagating the electro-dynamic action *from* the opposite pole as represented from S to W, that the wire will be urged to move in an *opposite* direction to the hands of a watch moving about the dial-plate. These relative movements have been explained in accordance with the Electro-dynamic Key (figure 32, page 235).

It remains here to verify all these theoretical calculations by practical demonstrations.

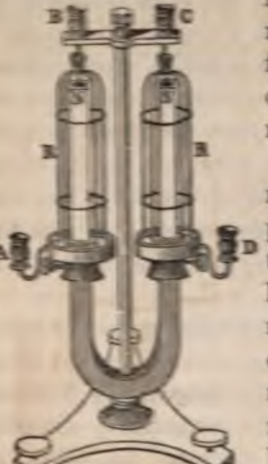
After the theoretical suggestions were advanced by Wollaston and others, demonstrating that the tangentially-directed impulses developed between conducting wires and the pole of a magnet, Faraday, with his accustomed sagacity, succeeded, in the year 1821, in exhibiting the end of a conducting wire revolving about the pole of a magnet, as exhibited in the annexed figure. Fully aware that if the conducting wire *b*, were extended the whole length of an approximated magnet *n*, the tendency of the portion of the upper end of the wire *a b*, to move in the same direction as the hands of a watch about the dial-plate, and of the lower end to move in an opposite direction to that of the same hands, these oppositely directed impulses would counterbalance each other, it required the exercise of much ingenuity to produce an arrangement of a current *limited to one pole of a magnet.*

Fig. 143.



This difficulty was overcome by Faraday by fixing a magnet in a vertical position in a vessel containing some mercury, and by hanging a conducting wire by a freely movable hooked joint *a*, directly over the vertical pole, with its lower extremity dipping into the mercury. The fluidity of the mercury allowed freedom of motion to the point of the wire immersed therein, whilst it served as a good metallic conductor to convey away the further propagation of electro-dynamic action beyond the reach of the other pole of the magnet.

Fig. 184.



The revolving movement of conducting wires about a magnet is now commonly exhibited by means of a light wire frame suspended by a pivot on the top of the vertical poles of a horseshoe magnet, as represented in the wood-cut.

Two light frames of copper wire are represented by R R, as supported by pivots resting on agate cups inserted in the tops of the two poles N and S. The lower tips of the wire frames dip into mercury contained in the two circular cisterns surrounding each prong of the magnet. The cups A and D are severally connected in one of these cisterns by a conducting wire, and the circuit of the current through the frames is insured by means of mercury cups, into which dip the lower ends of the wires projecting downwards from the upper cups B and C.

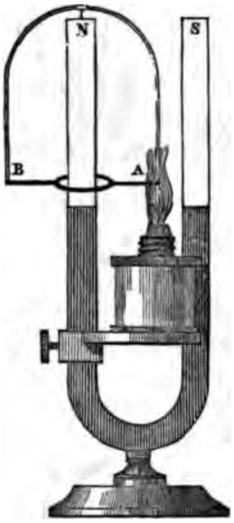
When the cups A and B are connected with the battery, the current flows through the vertical wires of the left-hand framework, which commences revolving; and when the current is transmitted between the binding cups C D, the right-hand frame will revolve. And when the circuit is extended through both frames, by connecting the binding cups A D with the galvanic battery, both frames will simultaneously commence revolving.

The following very beautiful and interesting experiment exhibits a remarkable *circular movement of the electric matter*, serving to propagate electro-dynamic action about the pole of a magnet, as has been recapitulated by Davy:—

"When a powerful horseshoe magnet was held horizontally with its north pole uppermost, and the wire from the negative side of the battery firmly pressed on the magnet, the positive wire being brought to within the striking distance, a brilliant *circular flame of electrical light was seen to revolve from left to right, in the same direction as the hands of a watch move about the dial-plate.* When the position of the magnet was reversed, the *flame revolved* *in an opposite direction, from right to left.* The appearance of the flame was not unlike that of the brush of light from an electrical machine received on a large surface, only much more brilliant."

Instead of a galvanic battery, the heat of a lamp may be employed to induce the excitation of thermo-electric currents adequate to causing a wire frame, like that represented by figure 117 at page 468, to revolve about the pole of a U magnet. In the former case, the natural terrestrial magnetic currents were relied upon. In the present case, the more immediately powerful influence of the artificially excited currents of a steel magnet is resorted to.

Fig. 145.



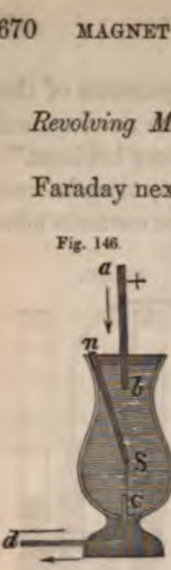
The transverse movement of the thermo-electric current ascending one side of the arch of the wire frame, and descending the other, neutralize the reciprocal action and reaction between them and the pole of the magnet on which the frame is hung. But this is not the case with reference to the opposite pole S, which reacts on only one of the vertical currents ascending the conducting wires nearest to it. This wire frame is caused continuously to revolve on the same principle as the wire frame revolves, as represented in the preceding figure.

In arranging this apparatus, the natural terrestrial magnetic currents may be made to coincide with, or to counteract, the artificially excited currents of the U magnet, accordingly as the instrument may be arranged in regard to the cardinal points of the compass, as has been explained particularly at page 468. The most advantageous position for the arrangement of the lamp is practically found to be at a point at right angles with the line connecting the two poles, and opposite to the pole on which the frame is mounted,—the position of the lamp in the wood-cut being arranged with a view to exhibiting more distinctly the parts of the machine.

In these experiments the conducting wires are shown to be revolving about the pole of a magnet. It remains now to show that the pole of a magnet will revolve about a stationary wire.

Revolving Movement of a Magnet about a Conducting Wire.

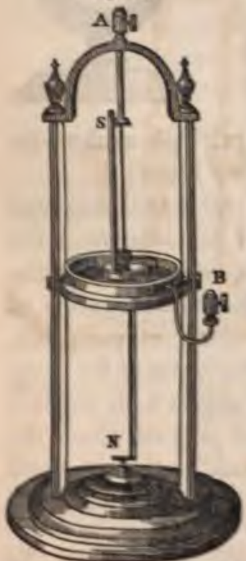
Fig. 146.



Faraday next succeeded in causing a magnet to revolve about a conducting wire, by immersing the magnet *n* S in a cup of mercury, as represented in the woodcut. The lower end is connected by a flexible wire with the conducting wire *d*, and the current is propagated from the battery through the conducting wire *a b*.

The magnet being immersed in mercury is obstructed in the freedom of its movements, which is not the case in the improved instrument represented in the next figure; where the magnet S N is bended to the form of the letter S, so as to allow of the arrangement of the straight piece of conducting wire from the binding cup A, connected with a galvanic apparatus, to conduct the current along the side of the vertical upper end of the magnet, as far down as the middle part, where it terminates in a branch immersed in a circular cistern of mercury surrounding the magnet. The object of this arrangement is to allow the tip of the conducting wire to remain immersed in the mercury, and to swing around in it without breaking the continuity of contact with the battery circuit. The current is thus caused to flow uniformly from the binding cup A, alongside of the S pole of the magnet, and to leave it at the middle part by the cup B, without acting on the lower half of the magnet.

Fig. 147.



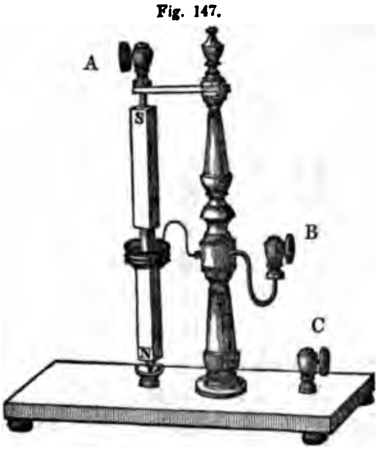
To keep the bended magnet in an erect position, the upper end S is secured by a ring or loop of wire to the vertical conducting wire, around which it has liberty freely to revolve, as about its axis of motion; whilst the lower end of the magnet rests upon a pointed pivot in an agate cup fixed in the base-board of the instrument.

This magnet will commence revolving rapidly at the instant the connection is formed with a galvanic battery. The direction of the rotations are dependent on the direction of the current, and on the respective N or S pole of the magnet presented to its influence.

If the current were transmitted alongside of both poles of the magnet throughout its entire length, no movement of it would ensue; for the dynamic impulses exerted on one pole would be counteracted by those exerted on the opposite pole; as has been previously explained in describing the electro-dynamic cylinder at page 240, figure 36.

Ampère and Savary caused *a magnet to revolve on its own axis* by means of an approximated battery current, as represented in the figure.

Fig. 147.



In the two preceding examples the magnet is caused to revolve by the action of an electric current traversing a *separate* conducting body. In the annexed figure an arrangement is exhibited wherein the separate conducting body is dispensed with, and the current is made to traverse the body of the magnet itself, thus demonstrating the most extraordinary fact, that a magnet may be made to revolve around its own axis *by the propagation of electric action along one half of its length.*

The magnet S N is upheld in its vertical position by means of a pointed wire inserted into a small cup formed in its upper end S, and containing a few drops of mercury (to insure a perfect contact), and by resting with its pointed end in a similar cup, connected by a wire beneath the board, with the binding cup C. The brass arm supporting the cup at A, is insulated from the brass pillar by some non-conductor of electricity. A small

circular cup or cistern of ivory, placed a
magnet, and containing a little mercury for
of the tip of the bended wire, and for all
freedom of motion to the magnet, is unit
B. By this arrangement a circuit from a g
transmitted at pleasure from A to B, and
wards or downwards, through one half
magnet; or from A throughout the whole
to C.

On connecting the cups A and B wit
galvanic battery, the current will be caus
upper half of the magnet, which will inst
turning about rapidly. Next connect the
battery, whereby the current will be mad
lower half of the magnet, and to produc
revolutions of the magnet in an opposite
nect A and C with the battery, and the n
remain unmoved, as the electro-dynami
upper half or pole S, to revolve in one
counteracted by the impulses urging the l
an opposite direction. If the cup B b
one pole of the galvanic battery, and bo
other pole, one half of the current will b
upper end of the magnet S, and the oth
lower end N, and the electro-dynamic im
produce an augmented velocity of rotation
of counteracting each other's impulses, an
static condition.

Let the reader regard the magnet in th
by itself, as exhibited in the figure, and
way of an electric current flowing along
ently of any adjacent conducting wire to
reacted upon by it, and he will probably l
hend how the impulses of electro-mechanic
in this case in conformity to the genera
mechanics, that "action and reaction are a
posite directions."

No movement of a *solid body* can resu
reaction between its own fixed parts unle

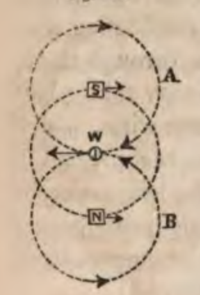
own force of cohesion. This spectacle, at a first glance, presents to view the apparent paradox of the exertion of a self-motive power in a mass of matter independently of the ordinary laws of action and reaction which are found in all other cases to govern the movements of matter.

When we cause the bended wire points of the revolving framework exhibited at page 403, to recede, we compare the action and reaction to that of the recoiling cannon; for we recognize both the propulsion or discharge of a current of electricity from such points, and also a current of particles of the adjacent air to move therefrom, which are palpable effects of mechanical action and reaction. And when we arrange one conducting wire near another, and cause galvanic currents to flow through them, we readily comprehend that action and reaction may take place between the currents and the respective conducting wires, which serve as their pathways. But we discover in the preceding experiment no such reaction of currents of the circumjacent air about the vertical magnet, and there is no adjacent conducting wire or electric current external to the body of the magnet itself which can act upon it, and be reacted upon thereby.

In attempting to comprehend the mode of action and reaction which ensures, in the preceding experiment, to produce the rapid rotation of the magnet on its own axis by means of the electric current flowing along it, we must look beyond the immediate influence of this current on the mass of the steel bar, and regard the direction of its divergent course at right angles to the line of the axis of the magnet, where the current either enters the end of the magnet through the approximated connecting wire, or where it leaves it through the conducting wire B, leading from the central mercury cistern. For this mode of electro-dynamic action and reaction admits of illustration by referring to the revolving movement of the mercury, in which the point of a conducting wire is immersed, as described at page 665, figure 141. The current *from* the axis of the magnet, as from the point of the wire in the mercury, represents No. 7 of the electro-dynamic key, page 235.

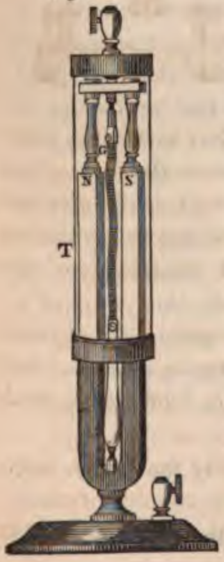
It has now been demonstrated experimentally that a conducting wire actually becomes urged by electro-dynamic forces to revolve about the pole of a magnet, and that the pole of a magnet becomes similarly urged to revolve about the end of a conducting wire. Upon the mechanical principle of equal action and reaction, it follows as a theoretical deduction from these facts, that if the ends both of the conducting wire and of the magnet be allowed freedom of motion to move in obedience to the impulses imparted to them, there must ensue the extraordinary phenomenon of a reciprocal revolving movement of a magnet and conducting wire about each other,—as will be presently illustrated.

Fig. 149.



As the direction of the action of magnetic currents circulating about the opposite N and S poles of a magnet, have been demonstrated to be in opposite directions, it is manifest on inspection that if the vertical wire be suspended between the two poles N and S of a horse-shoe magnet, as at W in the annexed figure, the electro-dynamic forces of both poles, as indicated by the dotted circles, will conspire to urge the wire W in a direction intermediate between the two approximated poles, as denoted by the short arrow affixed to W, whilst the current ascends; and in an opposite direction, when it descends toward the circular currents, denoted by the dotted lines A and B. The reaction of W on N and S is denoted by the lateral arrows affixed to each. This theory is verified by the following apparatus, which has been denominated the GOLD-LEAF GALVANOSCOPE. The instrument is an exceedingly sensitive test of the presence of electric currents of feeble intensity, by means of the swaying movements of the gold-leaf G, which is used in place of the freely movable revolving conducting wire, suspended over the vertical pole of a magnet, as exhibited in the figure at page 667.

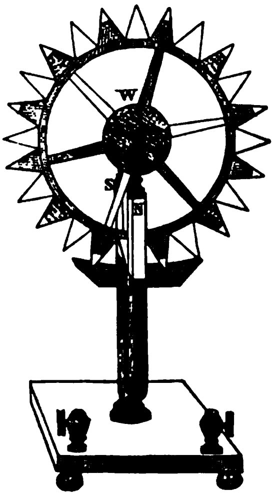
Fig. 150.



The gold leaf G has its upper end connected with a binding cup, and its lower end with another binding cup in the base of the instrument. To prevent the disturbance of this slip of gold-leaf by the agitation of the air, it is surrounded by a glass tube T.

The slightest electric current flowing through this slip of gold-leaf causes it to become curved forwards or backwards, according to the direction of the current which traverses it. In neither case is it urged directly toward one of the adjacent poles of the magnet, but in an intermediate direction, it being thrown forward from between them.

Fig. 151.



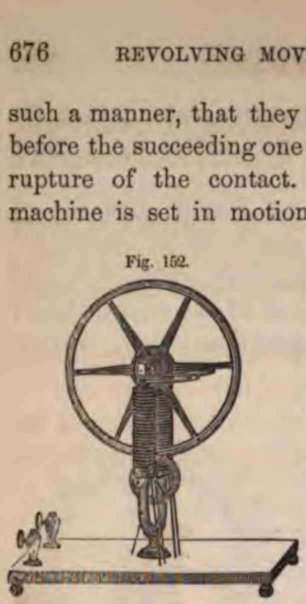
The wheel W is mounted between the two vertical poles of a horse-shoe magnet; and that portion of the arm of this wheel, which extends downwards from its axis to the mercury trough, represents the leaf in the preceding figure suspended between the two poles. The lower extremity dipping into the trough of mercury, is shown in the figure. The electric current being caused to ascend from one of the binding cups, fixed at the base of the instrument, through the vertical poles of the magnet to the axis of the wheel, from thence descends the arm of the wheel to the trough of mercury, which is insulated from the magnet, and through a conducting wire connected therewith, to the other binding cup. The arms of this wheel being successively urged forward, or backward, according to the direction of the current transmitted through them, it follows that a continuous revolution of the wheel will be maintained so long as the excitation of the latter continues.

It is not necessary to form the rim of this wheel with serrated teeth, as represented in the figure, for a circular disk of metal will cause it to revolve if substituted in place of the wheel with teeth or rays.

Some of the electrical phenomena of sparks and light developed by means of this instrument, are worthy of notice here.

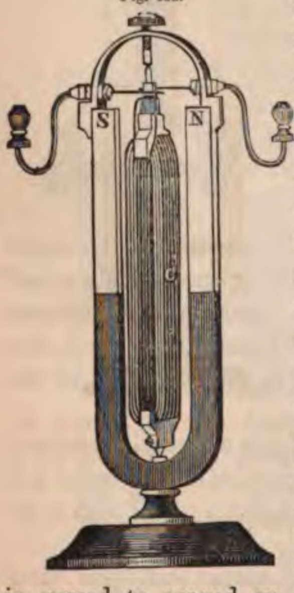
If the rays of the wheel be caused to dip in the mercury in such a manner, that they may each successively quit its surface before the succeeding one touches it, a spark will be seen at each rupture of the contact. Mr. Davis states that, when this machine is set in motion in the dark, so that it may be transiently illuminated by the rapid succession of these sparks, the revolving movement appears to be suspended, or to exhibit a quick vibratory movement. This optical delusion arises from the fact that the electric illumination is so extremely brief in its duration, that the wheel has not time to exhibit any appreciable movement during the electrical flashes, and each successive spark serves only to exhibit the wheel for an instant, in the successive stages of its revolving movement, as if at rest.

Fig. 152.



The continuous revolving movement of a wheel has been effected without the use of mercury, by means of the simple apparatus shown in the preceding figure. The electric current may be transmitted either upwards or downwards at pleasure through the arms of the wheels. The larger one rests in contact with the smaller under one, and the current passes from the connecting wire through the axis of the latter and vertically through the arms of both wheels, and through the axis of the upper wheel to the end of the wire coiled about two poles of the **U**-shaped electro-magnet. The arms of both the upper and under wheel are urged to move from between the poles of the **U** magnet, and a continuous rotation is thus kept up. In the following described instrument the current is caused to ascend on one side of the oblong coil of wire C and to descend on the other side, whereby a double electro-

Fig. 153.



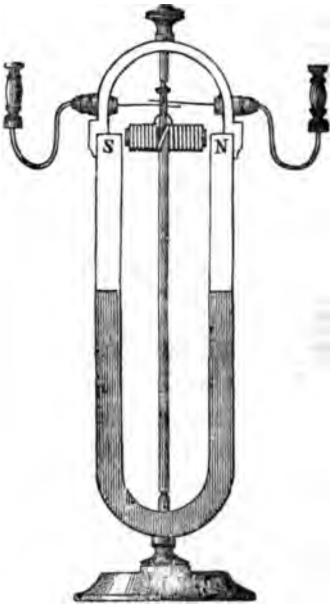
motive force is exerted, which causes this coil to revolve with the extreme rapidity "of *eight or ten thousand* revolutions in a minute," as stated by Mr. Davis.

The current-changers at A reverse the currents at every half revolution, so that there is both a reciprocal attraction and a reciprocal repulsion induced to augment the electro-motive power at each half revolution.

The humming sound produced by the rapidity of revolutions of this instrument may be heard at a considerable distance.

A very rapid rotation of a spindle on an axis arranged between the vertical poles of a U magnet is producible by the instrument represented in the woodcut. The wire coils, however, instead of developing all the electromotive impulses, (as occurs in the preceding case,) serve to render magnetic the soft iron cross-bar surrounded by the spirals, and to reverse its respective poles when the direction of the current is changed by the springs of the current-changer applied to the top of the vertical axis of the spindle.

Fig. 154.

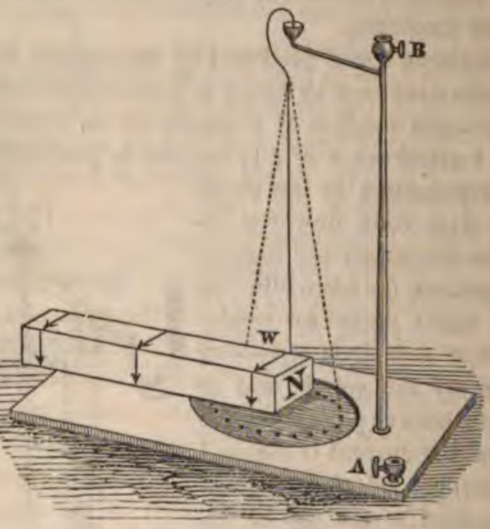


Having demonstrated the electric action in the direction of circles about the axes of magnetic bodies, it remains to notice an electric action which is found to take place exactly at right angles to the direction of this circular action, or in the line of the axes of magnetic bodies. The following experiment might lead to the supposition of the continual movements of currents in circles about a given point of the pole of a magnet *in every direction concentric thereto*, so as to complete a system of spherically arranged concentric circles.

It is important to disabuse the mind of the idea of such a complex transverse direction of a system of circles of electrodynamic action, as being utterly irreconcilable with the general simplicity of all the operations of natural motive-powers.

Instead of arranging the axis of the magnet in a parallel direction to the axis of the conducting wire as exhibited in the preceding figure 143, let the magnet be laid horizontally, and the current be still arranged vertically, as exhibited in the figure,

Fig. 155.



where W represents a copper wire suspended by its upper end, which is bended over so as to rest on the bottom of a metallic cup containing a few drops of mercury to ensure perfect contact therewith. The lower extremity of the wire dips into a shallow basin of mercury communicating with one of the poles of a galvanic battery by a connecting wire and screw cup A. The other screw cup B is connected with the opposite pole of a galvanic battery, thus propagating the electric current through the freely movable pendulous wire W, either upwards or downwards, at the pleasure of the operator.

When a current is propagated upwards, whilst the wire is arranged on the further side of the north pole of a bar magnet, about which the magnet currents circulate in the direction denoted by the arrows, it is manifest on inspection of the relative directions of the magnetic currents and of the ascending electric current, that they are moving in *similar* directions; and hence there must ensue an attraction between the wire and that side of the magnet; and as the combined currents of the further end of the magnet conspire to attract the wire, it will be urged to move toward the middle part of the magnet, until it gains an exact point of equilibrium of the currents which act at both ends of the magnet, on the principle which has been explained at page 240, of the movement of the conducting wire to the middle of the electro-dynamic cylinder.

Let the current now be reversed and caused to descend the wire W, when it will be perceived that the direction of this current will be opposite to that of the magnetic currents, and that a consequent repulsion must ensue, which will cause the wire to become moved from the centre clear past the end of the magnet. The current directed downwards in the wire, and on the hither side of the bar magnet, will now induce a reciprocal attraction between the wire and the hither side of the magnet, in the track exhibited by the dotted semicircle on the surface of the mercury.

If this semicircle be continued to the axis of the magnet, it will produce a complete circle of revolution of the wire about the pole of a magnet in a horizontal plane parallel with the direction of its axis, as exhibited in the figure.

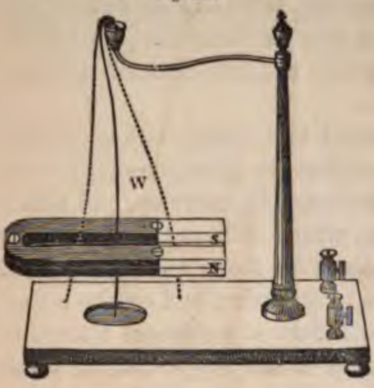
By comparing this direction of the revolution of the wire about the pole of a magnet with that of the direction of a revolving movement about its axis, as exhibited at page 667, fig. 143, it will be noticed that these respective circles present to view orbits of revolving movements, at right angles to each other.

By varying the relative position of the magnet and conducting wire, it may be experimentally shown that the wire may be caused to revolve about the pole of the magnet in every other intermediate orbit of revolution between a *circle about the axis*, and *parallel with the axis*, of the magnet, by means of the simple action and reaction between the magnetic currents circulating about the axis of the magnet, and of the electric current circulating through the axis of the wire.

It is not necessary to suppose that there is a continuous propagation of electro-dynamic impulses in every *direction* about the pole of a magnet, instead of being limited to *equatorial* circuits (page 240). To produce the revolving movement of a conducting wire in one direction about it, we have a rational scientific explanation, accounting for this apparently strange and incomprehensible phenomenon of electro-dynamic action.

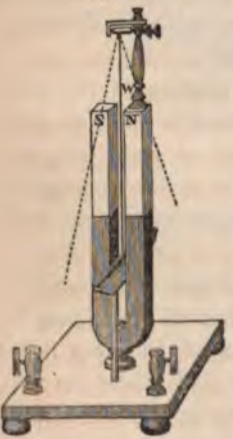
If the pendulous wire be suspended between the two poles of a U magnet, instead of being placed by the side of the single pole of a bar magnet, the action becomes doubly intense, as both poles in this case conspire to augment the effect produced.

Fig. 156.



When the wire is urged to move in either of the directions represented by the dotted lines, its lower extremity is thrown out of the mercury, and the contact being thus broken, and the battery circuit stopped, the wire falls back into the mercury, thus re-establishing the circuit and maintaining a continuous vibration of the lower extremity of the wire, like that of a pendulum swinging to and fro.

Fig. 157.

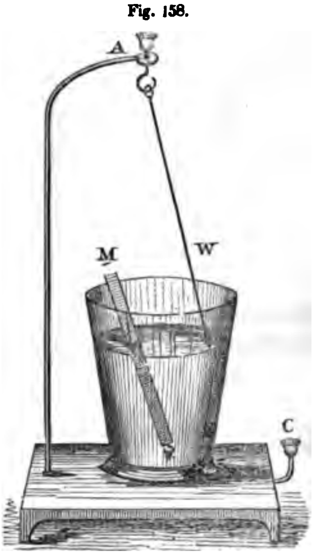


By arranging wires to swing freely between the poles of a U magnet, so that their extremities may dip in a vessel of mercury, to establish a galvanic circuit whilst they hang down perpendicularly, and to break the circuit whilst they are urged laterally like a vibrating pendulum, a continuous swinging of the wire may be kept up.

The Simultaneous Revolutions of a Magnet and of a Conducting Wire, reciprocally, about each other.

That there is an equal action and reaction between a conducting body and a magnetic body in the preceding experiments was originally demonstrated by Faraday, by means of a tumbler partly filled

Fig. 158.



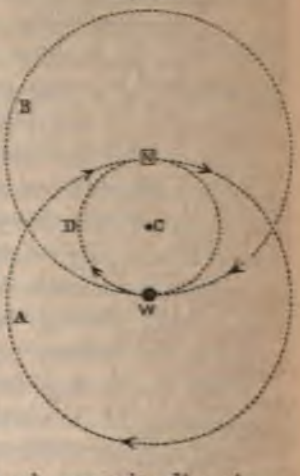
with mercury, as represented in the figure. The magnet M is immersed about half its length, in order that the current may affect only one pole. The conducting wire W is suspended by a hook and loop amalgamated to secure perfect conduction, and by this mode of suspension, is allowed freedom of motion, as by an universal joint. The magnet is similarly connected with the bottom by another conducting wire passing through it, and extended to the mercury cup C.

With this arrangement, on the transmission of a current, "the wire and magnet will both revolve in the same direction around a common centre of motion, each appearing to pursue, and to be pursued by, the other around the circumference of the circle described by their revolutions."

This experiment beautifully illustrates the fact of the lateral or tangential action of the electro-dynamic forces excited between an electric current moving crosswise of the electric currents circulating about the axes of magnets.

It will be noticed in the preceding experiment of the reciprocal revolution of the magnet and wire about each other, that the resulting movements *are not in opposite directions*, in accordance with the general law of the science of mechanics; but that, on the contrary, the revolving movements of each are in the *same direction*;—"each appearing to pursue, and to be pursued by, the other around the circumference of the circle described by their revolutions." But no discordance with this general law really exists in the peculiarly interesting principles of the action and reaction involved in this example of the exertion of impulses of electro-motive power. For we consider the conducting wire W, of which a sectional view is given, fig. 159, as urged to revolve about the pole N of the magnet in the direction of the short lateral arrow, whereby it would be caused to perform a complete circular orbit about N, as described by the dotted circle B, were it not that the pole of the magnet itself, as represented by N, has also similar freedom to move about W, as a centre of the circle of the orbit, in the direction denoted by the short lateral arrow A. Both of these combined movements produce the resulting movement about a common centre of motion between the two bodies, as represented by C with the dotted circle D drawn around it.

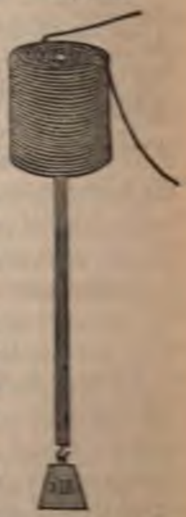
Fig. 159.



Although both bodies move about the same point in a common circular orbit, yet this result is in exact accordance with the established laws of electro-mechanical action and reaction in opposite directions.

This phenomenon of the continuous revolutions of two bodies about each other, as exhibited in the preceding experiment, merits more attention than has as yet been bestowed upon it. It developes principles of electro-dynamic action, producing the reciprocal revolving movements of polarized masses of matter about each other, such as are familiarly presented to our view in the minute apparatus of the lecture-room, and in the free space of the heavens; in the reciprocal revolving movements, about a common centre of motion, of our earth and the moon, of other planets and their satellites, and of the binary systems of stars.

Fig. 160.



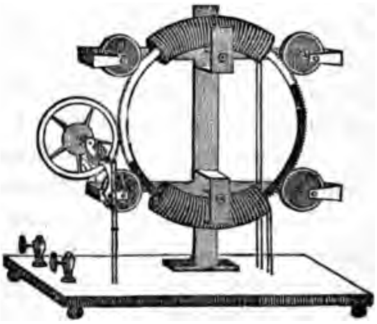
A machine for exhibiting a continuous revolving movement, on the principle described at page 244, and represented by the annexed figure, has been ingeniously contrived to move with considerable effective power.

Instead of a straight iron bar, a semicircular one has been used, united with a similar semicircular bar of brass, forming a complete ring, as represented by the shaded portion of the ring exhibited in the following wood-cut.

This ring is supported by grooved rollers to allow of its turning freely with little friction. Whilst the current is propagated through the lower spiral coil, the semicircular iron bar is drawn into it with such force as to impart to it a momentum sufficient to carry it forward to the spiral coil above it. At the moment the centre of the bar reaches the centre of the coil, the mechanism of a current-changer turns the action from the lower to the upper coil, which draws forward the bar; and this operation being continuously repeated by the self-acting mechanism, a continuous revolving movement is produced.

The circumference of the ring having teeth cut therein working into a cog-wheel shown in the figure, serves to operate the mechanism, to change the current at the proper moment, and also to develope electromotive power.

Fig. 161.



Very numerous other machines for producing revolving movements of mechanisms by electro motive power have been introduced into use by ingenious inventors. They are to be found in the manufactories of electro-magnetic apparatus. A description of them the reader may find in a work published by Daniel Davis, junr.

ELECTRO-MAGNETIC ENGINES CONSIDERED AS AVAILABLE SOURCES OF MOTIVE POWER.

The first successful attempt to apply the dynamic impulses of electricity for imparting regular motive power to operate machines, was made by William Sturgeon, in England. The next original invention by which an independent motion was obtained from electro-magnets, was that of the vibrating working beam, like that of a steam engine, produced by Professor Henry. Dr. Ritchie's revolving magnet appears to have been the next in order of date. The rotary electro-magnetic machines of Dr. Edmonson of Baltimore, and of Davenport, invented in Vermont, were soon after exhibited.

Professor Page has subsequently distinguished himself by his numerous experiments in this new branch of science in the United States. He states (Silliman's Journal, January 1, 1839), "I have had sixteen different models constructed, each involving distinct principles. From all these experiments the inference is still the same, viz., *the fewer the magnets and the smaller their size, (with certain limits), the greater the ratio of the mechanical power obtained.* Such experience as this appears discouraging, but it is by no means sufficient to prove the experiment infeasible. The numerous failures are such as have been incident to the prosecution of all inventions in their early stages." He continues, "It is not to be presumed that in the present age, or perhaps ever, shall we arrive at a power from electro-magnetism, which will supplant the steam engine in its grander operations. Incalculable benefit would be conferred on society if a new and simple mechanical power could be procured, available from that of a single man to that of one or two horses."

The largest electro-magnetic engine, according to Mr. Noad's statement, was made by Henly, with a wheel 7 feet in diameter, and weighing four hundred and fifty pounds. The galvanic battery contained 13 cwt. of metal, and the consumption of the sulphate of copper in a single week was 6 cwt., merely for making experiments. This machine was speedily abandoned as too costly to compete in economy with steam-power.

An interesting experiment of the propulsion of a boat on the water by an electro-magnetic engine was tried in the year 1838, by Professor Jacobi, in St. Petersburgh, at the charge of the government. "The vessel was a ten-oared shallop, equipped with paddle wheels, to which a rotatory motion was communicated by an electro-magnetic engine. The boat was 28 feet long, 7½ broad, and drew 2¾ feet of water. In general there were ten or twelve persons on board, and the voyages were continued (on the Neva) during entire days." The Professor states as the result of his experiments, "that a battery of sixty-four pairs, each having 36 square inches of surface, and charged according to the plan of Grove, with nitric and sulphuric acids, went *against* *the stream* at the rate of three miles an hour, producing a power probably equivalent to that of *one horse.*

So recently as the year 1842, a large *Electro-magnetic Locomotive Engine* was constructed by Mr. Davidson, and tried on the Edinburgh and Glasgow railway, the account of which, with drawings, was published in the Practical Mechanics' and Engineers' Magazine for November, 1842. The carriage was 16 feet long and 6 feet broad, and weighed above 5 tons, including the apparatus of batteries, magnets, &c. This Electro-magnetic Locomotive was propelled by means of electricity with a velocity of only about 4 miles per hour, which was estimated to be less effective than about $\frac{1}{6}$th part of the power of a horse, exerted in moving a similar carriage over a smooth road.

In all these attempts to render available important mechanical impulses from the recoil of the groupings of atoms of zinc to their natural static condition of oxides or ores in the galvanic battery, as a substitute for the impulses of steam-power available by the similar recoil of groupings of atoms of fuel in the furnaces of steam engines, it has been found that the *reaction of secondary electric currents*, excited in the approaching parts of the apparatus, have essentially counteracted the electro-motive power. It has been previously explained, in treating of Inductive Excitation, that there cannot be one portion of matter moved near another without disturbing the electro-static conditions of both bodies, and developing dynamic action. Unfortunately for the success of experimenters, this dynamic reaction increases with the speed of the moving parts of the mechanism employed, until the intensity of it arrests the velocity.

These reacting secondary currents are practically found to subserve the purpose of a *self-compensating principle, regulating the speed of movement of the approximating and receding parts of all mechanism impelled by electro-motive agency.*

This fact of the inductive excitation of counteracting secondary currents in an opposite direction to a primary one, appears to be one of the most surprising, as it proves to be one of the most important, facts established by discoveries in the science of electro-dynamics. For we may apply this principle, learned from operating the tiny revolving apparatus of the lecture-room, as a newly-discovered law adapted to governing the movements of the revolving bodies constituting the vast electro-magnetic apparatus of the mechanisms of the heavens. Admitting this principle, the planets must necessarily continue to revolve with uniform velocity about the sun.

This difficulty of *reacting* secondary currents, Professor Page appears to have avoided, by adopting the plan of operating an electro-magnetic engine, described at page 244, figures 38 and 39. To aid him in his experimental attempts to render electro-magnetism an available source of motive power, the Congress of the United States have appropriated the sum of twenty thousand dollars, as before stated. The following extracts from public journals afford some knowledge of the progress which has been made in these interesting experiments.

"Professor Page, in the lectures which he is now delivering before the Smithsonian Institution, has exhibited a bar of iron weighing one hundred and sixty pounds, which was made to spring up by magnetic action, and to move rapidly up and down. The force operating on this bar, he stated, averaged *three hundred pounds*, through ten inches of its motion. He said he could raise this bar one hundred feet as readily as through ten inches, by arranging a succession of helix coils, one above another, and by causing the electric current to circulate through them successively, as fast as the bar could follow the impulses."

"He then exhibited his engine of between four and five horse-power, (operated by a battery contained within a space of three cubic feet,) with two feet stroke, the whole weighing about one ton. It made 80 strokes per minute, whilst driving a circular saw ten inches in diameter, sawing up boards into laths."

He has since experimented with a locomotive engine on the Washington railroad. The engine was propelled at the average rate of ten or twelve miles in an hour.

"With all the imperfections of the engine, the Professor supposes the consumption of three pounds of zinc per day would produce one horse-power. There were yet practical difficulties to be overcome. The battery has yet to be improved."

This experiment certainly manifests a great superiority over any previously made; for, according to statements made by Joule and R. Hunt, in England, "one horse-power is obtainable in an electro-magnetic engine, at the cost of forty-five pounds of zinc, in a Grove's battery, in twenty-four hours. The most improved applications of magnetic power must be nearly twenty-five times more expensive than steam power," as affirmed by them.

Professor Page stated before a meeting of the American Association, that the cost of the zinc consumed in producing one horse-power, did not exceed twenty cents per day, whilst he could keep it in full action; but that he was yet dubious of the continued power of the battery, which attains its maximum in about this period, and then decreases.

The curious reader, who may wish to extend investigations of the efficiency of Electro-magnetic engines as prime movers, or sources of motive power, is referred to the following works.

The Annals of Electricity, a periodical journal, contains accounts of the numerous Electro-magnetic engines which have been produced by different experimentalists.

Sturgeon's Electro-magnetic Engine, for turning machinery, vol. 1, page 75.

Jacobi's paper on the Application of Magnetism to the moving of Machines, with a description of an Electro-magnetic Engine, vol. 1, pages 408—419.

Joule's Electro-magnetic Engine, vol. 11, page 122.

Davenport's Electro-magnetic Engine, vol. 11, page 257, Silliman's Journal, April 1837.

Lockey's Electro-magnetic Engine, vol. 3, page 14, Silliman's Journal.

Page on Electro-magnetism as a Moving Power, vol. 11, page 554, Silliman's Journal.

Page on Electro-magnetic Engine, vol. 49, page 131, Silliman's Journal.

Joule's Improved Electro-magnetic Engine, Elec. Mag. Magazine, vol. 4, page 203.

Clarke's Electro-magnetic Engine, vol. 5, page 33.

Wright's Electro-magnetic Engine, vol. 5, page 108.

Clarke's Electro-motive Engine, vol. 5, page 304.

Jacobi's Communication to the Meeting of the British Association in Glasgow, in September 1840, vol. 6, page 162.

Davidson's Electro-magnetic Locomotive; Engineer's Magazine, part 14, page 48.

Taylor's Electro-magnetic Engine; Mechanic's Magazine, vol. 32, page 694.

Watkins' Electro-motive Engine; Philosophical Magazine, vol. 12, page 190.

By reference to the above-named works, it will be found that a great variety of ingeniously devised machines have been constructed to be operated by electro-motive power.

In comparing the economy of the use of electricity as a source of natural motive power with that of steam-power, a glance at the relative costs of the materials employed to excite the phenomena of electricity and of heat, is sufficient to convince the reader that great improvements remain to be made in the modes of exciting electricity, before it can become substituted in place of steam. The metals and acids decomposed chemically in the battery troughs or cups, are rare; and are obtainable in small quantities by a very considerable outlay of capital, as compared with the procurement of the carbon consumed in the furnaces of steam-boilers. A ton of zinc costs nearly 100 fold more than a ton of mineral coal, in many of the principal countries of the earth.

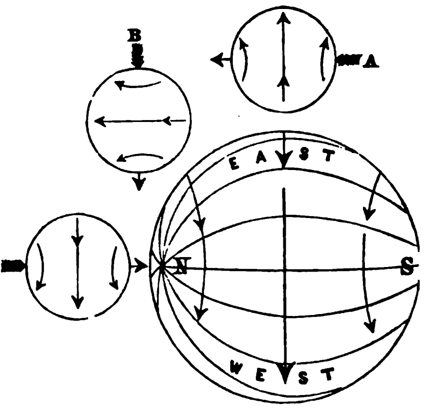
It is to be remembered, in these calculations, that about ten pounds of carbon are necessarily burnt in a smelting furnace to reduce one pound of zinc to its constrained static condition of a pure metal; and consequently one pound of this metal represents ten pounds of coal, the one adapted for the furnace and the other for the battery cell. In addition, costly acids are requisite. If we consider the steam engine and furnaces thereof to be now brought to a state of perfection, and to admit of no further improvement for developing a greater extent of motive power by the combustion of a given quantity of coal (which is probably not the case), then we have a fixed basis of comparison by which the advantages of employment of electro-magnetic engines may be estimated. According to Dr. Page's statements, could the power of the galvanic battery be sustained, the result of an equal economy appears to have been attained. In the latter case the superior portability, compactness, security from fire, and the saving of the attendance of an engineer, are conclusive arguments in favor of electro-motive power, where small steam engines may be required.

This subject we must leave, as we have found it, in an experimental state of progress.

OCEAN TIDES AND GRAVITATION ASCRIBABLE TO ELECTRO-DYNAMIC ACTION.

Electro-dynamic action in the modified form of electric currents has been demonstrated, page 226, figure 24, to be circulating from east to west about the earth's surface. The directions of these currents have been represented by the *equatorial* arrangement of the arrows about N S, and about A. It has been previously noticed that were all the planets of the solar system arranged in the space of the heavens with their respective *polar* currents facing each other, as shown at C, they might all be determined to move *toward*, instead of revolving, as they actually do, *about* a common centre.

Fig. 162.



The very fact of this *equatorial* arrangement of the planets in relation to each other, appears to be conclusive evidence of the establishment of a principle of reciprocal electro-dynamic action and reaction between them, such as has just been shown to be actually developed between the revolving parts of the apparatus described in the preceding chapter.

The direction of the revolving movement of the moon about the orb of the earth is opposite to the direction of the electric currents circulating from east to west about its surface. This peculiar constrained direction of the revolving movement, imparted to the moon, appears to have been designed expressly to induce circulation of electric currents in SIMILAR DIRECTIONS about the approximated sides of the earth, and of the moon.

By applying the principle of "attraction between similarly directed currents," established in the preceding pages, to the regulation of the dynamic action which must reciprocally take place between the huge masses of matter in the free space of the heavens, as well as between the freely movable parts of the apparatus of the lecture-room, which we have just been engaged in describing, there appears to be traceable a sufficient cause of electro-dynamic excitation for producing the phenomenon of Ocean Tides.

Considering that the portions of arcs of *equatorial* circular currents moving in opposite directions on opposite sides of the earth neutralize each other's action relatively to the centre of the earth (page 252, figure 46), there will remain only the exterior portion of the terrestrial currents on the surface nearest to the moon to be taken into account, as acting thereon. And the same rule being also applied to estimate the resultant attraction of the moon for the earth, as made up of the resultant electro-polarizations of the component atoms of the mass, the following calculations may be made.

The currents about the sides of the moon and of the earth nearest to each other, must induce attraction between their respective surfaces, and a consequent elevation of freely movable fluid ocean water, on the principle that similarly directed currents induce reciprocal attraction. But at the same time these currents, moving in similar directions between the approximated sides, move in opposite directions to the portions of the currents circulating respectively about their remote sides. Consequently a repulsion must ensue between these oppositely moving currents; and freely movable substances, like ocean water, must become urged reciprocally from such currents, and from each other's centres.

By this simultaneous attraction between the nearest surfaces of the moon and earth, and repulsion between these same surfaces and their remoter sides or surfaces, there appears to be an adequate cause for the two opposite tidal waves, rising simultaneously, on the two opposite surfaces of the earth.

By the popularly-adopted Theory of Tides, the solid centre and mass of the earth is considered to be drawn away from the inert mass of the ocean water, leaving it behind in an elevated accumulation on the side farthest from the moon. If this supposition were true, the solid mass of the earth must have a continuously accelerated velocity toward the moon. The laws of universal gravitation also would not be applicable to fluid water. Both of these suppositions are false, and consequently the theory founded on them cannot be true. The same weight of ocean water on the side of the earth farthest from the moon must be as powerfully attracted thereby, as an equal weight of solid rock or sand. The elevation of tides, simultaneously, on opposite sides of the earth, cannot therefore be ascribed to a general law of gravitation, which has reference only to the mass, and not to specific parts of a mass. There seems to be no other rational explanation available, than the reciprocal action and reaction of the oppositely-directed currents, circulating about the opposite sides of electro-polarized spherical bodies.

It admits even of calculation that the tides on the side of the earth farthest from the moon should be less elevated than on the side nearest to the moon. For the difference of intensity of the electro-dynamic action being diminished in the inverse ratio of the squares of the increased distances, the intensity of the electro-dynamic action of the moon on the nearest side of the earth must exceed that on the remoter side of the earth, in the ratio of 54,289 to 58,081. This result is arrived at, by taking the mean distance of the moon from the earth to be 237,000 miles, and the diameter of the earth to be 8000 miles.

If freely movable salt water, which is a good conductor of electricity, be made to serve as the pathway of an electric current, instead of the two swinging wires (figure 29, page 220), there is every reason to suppose from analogy, that attraction must become similarly developed between two portions of water; although some experiments instituted by me failed to demonstrate the attraction, from a want of time to complete them properly.

The fact is readily demonstrable, that a body serving like a conducting wire to propagate electro-dynamic action from east to west on any part of the earth's surface, becomes urged toward the earth's centre by an appreciably augmented force; and the same body will be less forcibly urged toward the earth's centre when it serves to propagate a current in a direction from west to east.

The vertical dipping of one end of the magnetic needle at the pole of the earth, serves to illustrate this principle of the prevalence of a modified electro-dynamic action, coinciding in direction with "gravitation." As the reciprocal polar action between bodies is more intense than the equatorial action, it would afford an interesting proof of the truthfulness of these laws of electro-dynamic action, if a magnetic needle were weighed by a very delicate spring balance at the earth's equator, and then at one of the magnetic poles of the earth, where the needle assumes a vertical, instead of a horizontal position.

So far is the introduction of an electro-dynamic theory of gravitation from being contrary to Newton's opinion on the question of the cause of the mechanical force producing this mechanical effect, that it appears to be absolutely called for by the suggestions of this illustrious philosopher.

In his letter to Dr. Bentley, Newton expressly disclaims all idea of the possibility of the propagation of mechanical impulses of gravitation, without some intervening material medium adapted to the propagation of such impulses. He remarks in this letter, "that gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance, through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has, in philosophical matters, a competent faculty of thinking, can ever fall into it."

If the electro-dynamic theory be not truthful, it will serve to explain the observed phenomenon of gravitation better than the popular theory of an "inherent force of gravitation," which Newton has pronounced to be an "absurdity."

These investigations are more appropriate subjects of study in the science of mathematics, based on astronomical observations of the movements of the heavenly bodies; whereby the laws of electro-dynamic action must be finally verified, or proved to be inapplicable to their movements.

ELECTRO-METALLURGY.

The term Electro-Metallurgy, denotes a new and beautiful application of the science of electricity to the useful arts. It has already become extensively introduced into the workshops of gold and silver smiths, for the purpose not only of gilding and silver-plating vessels in use for various household purposes, but even for *making solid silver vessels*, which are formed on one side of the surfaces of copper models. This process has also been extensively employed for depositing a film of gold upon various trinkets made of copper or brass, denominated "jewelry."

It is only necessary to render the surface of the most delicate bodies, or tissues, conductors of electricity, (such, for instance, as flowers, leaves of plants, the fibres of wool, and of hairs, and even the fibres of lacework,) to encase them with a coating of pure glittering gold or silver. The forms of butterflies, and of minute insects, may be so completely covered with these durable metals, that they may be preserved with exquisite clearness and precision, and thus perpetuated like the enduring statues of the human form, modelled in bronze and marble by the chisel of the sculptor.

Delicate objects, such as flowers, insects, &c., which cannot withstand the action of a brush to receive a coating of plumbago, may be rendered sufficiently good conductors by being dipped in a weak solution of the nitrate of silver, and afterwards exposed, whilst moistened thereby, to the fuming vapors of phosphorus confined under a tumbler or bell-glass. The vapor of phosphorus is obtained by putting some phosphorus dissolved in alcohol in a watch-glass, placed beneath an inverted tumbler or other glass vessel.

By this operation the silver, forming the nitrate of this metal, becomes restored to its pure metallic state, in a thin film, overspreading all parts of the object that has been immersed therein; and consequently all the surfaces of any such objects are rendered conductors of electricity, and capable of receiving a deposit of the metal.

The brass wheel-work and springs of chronometers have been recently gilded by this process; and Mr. Walker states that one experimentalist "has undertaken to gild all the movements of a watch, even whilst in motion."

"An engraver in Geneva has used a deposited coat of gold, instead of varnish, on plates intended for ordinary etching; and has succeeded in tracing his designs most accurately through this exceedingly delicate layer."

The thin films of gold deposited being semi-transparent, this process has been resorted to for protecting and permanently fixing Daguerreotype pictures, thus preserving them from the destruction that results from the least touch or rubbing of their surfaces.

Numerous patents have been taken out in England for the application of the preceding described processes to various practical purposes of coating manufactured articles with copper, nickel, lead, zinc, &c.;—of etching on iron, steel, silver, and gold, &c.;—of embossing copper rollers for printing calicoes, and coating pipes, and even "boilers and stewpans," through the agency of galvanic electricity.

The thickness of the coating of silver, gold, and copper deposited by an equal current of electricity in equal times, has been found to be in the relative proportions of 108 grains of silver, 99 grains of gold, and 32 grains of copper; which is in accordance with the relative chemical equivalents of these several metals.

By variously modifying the *intensity* of the galvanic currents, the *quantity* of it, the *strength of the solutions*, and the *period of time* of the immersion, any desired thickness of the silver may be encrusted on the articles plated therewith.

In order to ascertain the quantity of silver plated on the articles subjected to this process, it is only necessary to weigh them before immersing them in the solution, and after they are withdrawn therefrom; and the excess of weight in the latter case will give the true weight of the silver deposited.

The orderly system in which atoms of fluid solutions become arranged into beautiful symmetrical crystals, has been adverted to at page 84, figures 5 and 6; and the action of galvanic batteries in electro-polarizing atoms and in separating them from a solid bar of metal connected with the delivering or positive pole, and transferring them to the opposite receiving pole, in freshly grouped crystalline arrangements, has been described (page 531) in the chapter on the formation of mineral crystals in the earth by electrical agency. The state of solidity re-established among these crystalline groupings has also been referred to in the chapter on Cohesion and Chemical Affinity, page 525.

The origin of the discovery of this new branch of science is traceable to the deposition of copper on the plates of galvanic batteries, which has been detailed in describing the different kinds of batteries. The earliest experimenters with Daniell's battery found that a coating of copper became cohesively attached to the copper plate of the battery, as if the new deposit constituted a part of the original copper plate; and they sometimes found that the deposited copper could be flaked off, exhibiting impressions on the surface of the sheet thus flaked off, of the minutest indentation or scratch on the battery plate, precisely as if the particles of copper had been reduced to a molten mass and poured upon the battery plate, as upon a mould to obtain a copy of its indented surface.

This remarkable fact attracted no particular attention for several years, until so recently as the year 1837; when Professor Jacobi, in St. Petersburgh, and Mr. Spencer, in Liverpool, simultaneously directed their attention to rendering available this establishment of the cohesion among the particles of metals in a *cold state* by electric agency, by means of the decomposition of zinc in galvanic batteries, instead of employing the same agency in the modified form of heat produced by the decomposition of fuel in furnaces in the usual way of melting and casting metals.

Mr. Spencer described, in a paper read before the Liverpool Polytechnic Institution, the accident by which his attention was particularly directed to the subject. "When about to make an experiment, I had not a slip of copper at hand to form the negative end of my arrangement, and, as a substitute, I took a penny, and fastened it to one end of the wire, and put it in connection with a piece of zinc in the cell of Daniell's battery. Voltaic action took place, and the copper coin became covered with a deposition of metal in a crystalline form. But when about to make another experiment, and being desirous of again using the piece of wire, I pulled it off from the coin, to which it was attached. In doing this, a piece of the deposited copper came off with it; and on examining the under portion, I found it contained an exact mould of a part of the head and letters of the coin, as smooth and sharp as the original on which it was deposited."

This fact having led Mr. Spencer to institute a course of experiments for perfecting this process, he finally succeeded in producing beautiful specimens of medals, coins, and other objects moulded in brilliant copper, of greater purity than cast copper.

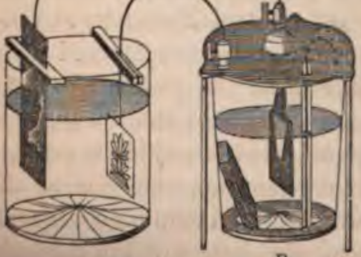
This discovery was applicable only to the moulding or copying metallic substances, which are conductors of electricity. The copper, silver, gold, &c., could not be precipitated on the surfaces of bodies immersed in the cell of a Daniell's battery, unless such bodies served to receive and transmit the electric current. Mr. Murray devised the plan, now in common use, of coating the surfaces of non-conducting bodies with blacklead, (plumbago,) which being a good conductor, allowed the metallic solutions to become deposited on moulds of wax, plaster of Paris, and, indeed, of every kind of substance coated therewith.

By the labors of Jordan, Mason, Smee, Murray, Elkington, Shaw and others, various improvements have been made in perfecting this process, and rendering it available as a newly-created, beautiful, and useful art.

The deposit of metal is very imperfectly accomplished by means of a single cell when used "to do the work of both battery and depositing apparatus." The use of a separate battery and a separate vessel for containing the medal or moulds to be coated with metal, enables the experimenter to control more perfectly the execution of the work.

For accomplishing electro-plating on a small scale, Mr. Daniel Davis recommends the use of Smee's battery, of "a new and improved construction," which is represented in the annexed figure, and which is denominated the "*mercurial*," or "odds and ends" form.

Fig 163.



In the bottom of the glass jar B, a little mercury is poured, in contact with which plates of zinc, or scraps of waste zinc, may be placed in the vessel. Beneath the screw cup at the centre is suspended a plate of platinum. The current is induced from the zinc to the central platinum plate, and from thence through the conducting wire inserted in the top of the central screw cup, to the plate of metal shown in the adjacent glass vessel. From this plate the direction of the current in its circuit is through the liquid to the medal or other body to be covered with the deposit of new metal. By the arched connecting wire soldered to the medal, &c., suspended thereby, the battery circuit is completed to the screw cup on the top of the cover of the battery, and thence by another short piece of conducting wire down through the liquid and insulated therefrom in the glass tube, to establish contact with the mercury at the bottom of the vessel.

This cheap and simple form of galvanic battery I have had occasion to notice in successful use for depositing raised protuberances of copper on the copper cylinders, commonly used in the process of calico printing.

The sheet of metal opposite the medal, or other body to be coated, is first immersed in the vessel containing a solution consisting of the proportionate parts of 2 ounces of sulphate of copper and 1 ounce of sulphuric acid to every 15 ounces of water. The battery is charged in the usual way.

A remarkable electro-dynamic action now ensues on the copper plate immersed opposite to the medal; for the electric current serves to facilitate the disintegration, or chemical dissolution, of the atoms of the sheet of copper, as fast as the copper is deposited on the opposite medal, so that the process of transference of the particles of copper from the copper plate to the medal will continue to go on, until the cohesion of the whole mass of particles composing the plate is counteracted, and re-established among them, after being conveyed away to encrust the medal.

This fact well deserves a passing notice, as demonstrating that the phenomenon of cohesion is not only caused to cease, but also to become re-established as an effect produced by electro-dynamic agency.

It is found that during the process of the dissolving of the delivering or positive copper plate, a considerable quantity of black sediment becomes precipitated, which would deteriorate the purity of the deposited metal, were not the face of the medal presented in a vertical position. The solution requires to be stirred up occasionally to maintain equal strength throughout the liquid; and any air bubbles that may gather upon the body receiving the deposit, must be carefully removed.

By means of the electrical action above described, the metals may admit of being precipitated in three different conditions, according to contingent circumstances of the electric action, viz., in a black pulverulent deposit: in a regular malleable coherent condition: and in a highly crystalline condition. These distinct conditions are the results of the decomposition of other compound elementary substances, combined with the metals in solution. When the water is decomposed, hydrogen is evolved at the negative pole simultaneously with the deposit of metal at the positive pole, where the black deposit becomes manifest. The evolution of hydrogen, and the consequent black deposit of metal, becomes augmented from the following causes, according to Mr. Smee's observations.

By increasing the intensity or quantity of the battery; by increasing the size of the delivering positive pole, or by decreasing that of the receiving or negative body to be coated; by increasing the heat of the solutions, by weakening their strength, and by adding too much acid.

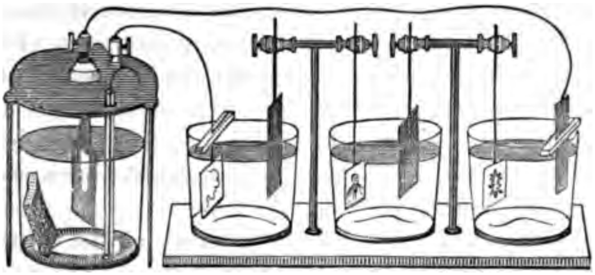
On the contrary, the tendency of hydrogen to evolution may be diminished, and the beauty of the crystalline arrangement of the atoms of metal deposit correspondingly improved, by using electric currents of less intensity or quantity; by extending the surface of the receiving body or pole, or by diminishing that of the delivering pole; by separating more widely asunder the poles; by saturating the solution, and by diminishing its temperatures. More failures of successfully accomplishing this process occur from using too intense an electric current, than from any other cause.

When the process is well conducted, the copper deposited is of great purity, and bright color; having superior hardness and durability for service for the purposes of printing, in the form of engraved plates and types, than the ordinary copper of commerce.

The time required for accomplishing the process of encasing the surface of a body with a thickness of $\frac{1}{16}$th of an inch, may be abbreviated by means of the previously described methods to one day, or extended to several days, if the process be performed in ather.

To accomplish the deposit of an ounce of new copper, it is found that a little more than an ounce of zinc is necessarily dissolved from the zinc plate of the battery. To reduce the expense of this decomposition of the zinc, it is usual to arrange a number of articles to be simultaneously plated, in a series of vessels or cells, which are connected by conducting wires to form one continuous battery circuit, as shown in the figure.

Fig. 164.



To insure conductibility of the liquid, more acid must be used in the several cells than where only one is used, and less of the dissolved blue vitriol. Economy of manipulation is available from the use of a series of cells, as the same electric current which will operate on the materials in one cell, will serve simultaneously to operate upon the materials distributed in a series of cells, the conductibility being maintained by adding more acid as above stated. By this arrangement several ounces of fresh copper may be deposited by the consumption of one ounce of the zinc of the battery plate, and with nearly the same quantity of blue vitriol acid.

In the figure, the central screw cup is connected with the plate of platinum, suspended in the liquid of the battery, and also with the further copper plate, which serves as the delivering pole, arranged opposite to the medal to be coated with copper. As has been before stated, the atoms of metal, constituting the sheet of copper, are electro-mechanically separated by the agency of the electric current transmitted through it; and being thus set free from their fixed state of cohesion, they are transferred to the receiving surface of the medal, and become there oppositely polarized, and thus restored by electrical agency to their original metallic state of cohesion, as a solid glittering metal. To plate steel or iron with copper, the sulphate of copper is dissolved in a solution of cyanide of potassium, which is not decomposed by the steel or iron when the surfaces are perfectly clean.

Sheets of iron are coated with zinc by means of the process described already, as an article of commerce known as "galvanized iron."

Among the most important applications of this new branch of science to the useful arts, is the formation of impressions of wood-cuts for printing, which "retain all the purity and sharpness of the original outlines, and thus as many fac-similes as we like may be taken of the original, without any difference being perceptible between the first and last impressions." As ordinary wood-cuts are soon worn out by use, copper type in an unlimited number may be thus formed, each quite equal to the original.

In describing the excitation of electricity by magneto-electric machines (page 301, fig. 64), it has been recapitulated, that these machines are employed in the workshops of Birmingham and Sheffield, in preference to galvanic batteries, for accomplishing the process of electro-plating on a large scale. The specification of Woolrich's patent magneto-electric machine is published in the 38th volume of the Mechanics' Magazine. Mr. Prime states that about five ounces of silver per hour may be deposited by each machine, and that a very little extent of steam power is required to operate a machine. The wear is very trifling, and the magnets retain their power without appreciable diminution.

The most admirable perfection has been attained in the beauty, and skill in the manufacture, of silver-plated wares, since the application of the principles of this new science has been extended to its advancement. "No manufacture, in the whole course of its history," as it has been observed, "presents greater contrasts than the manufacture of plated wares within two or three years." The skill of the artist is now exercised in the production of designs of the most tasteful proportions, and bold ornamental reliefs of raised or embossed figures on the wares produced by this new process of art."

It is found that the galvanic process of gilding can be effected with far greater economy than the old mercurial amalgamation process, whereby the health of so many ingenious artists has been destroyed; and it has done much, as it has been well observed, if it effect no more than "to banish an art whose practice is inseparable from human sufferings."

Electro-etching in Copperplate Engraving.

In describing the process of electro-plating with copper, as detailed in the preceding pages, it has been shown that the particles of a copper plate constituting the delivering or positive pole of a galvanic battery, are transported atom by atom across the acid solution in which the plate is immersed, and are reunited in a perfect state of cohesion or solidity upon the surface of the body opposite to it, which constitutes the receiving or negative pole of the battery. If the surface of this copper plate be coated with wax, varnish, or any other non-conducting substance, the transference of the particles of copper from the surface of the plate will be entirely prevented. Hence, the fact becomes manifest, that if certain spots or lines, in the form of engraved furrows, be scratched through the surface of this coating of varnish so as to lay bare the naked copper beneath it, the particles of copper may be transferred from such bared portions of its surface leaving cavities therein, precisely as occurs in the process of engraving copper plates by ETCHING, with acids poured upon them.

Thus, this *electro-mechanical* process precisely resembles the process of chemical action of acids upon the copper; and whilst it serves as an expeditious and beautifully simple mode of executing this style of copperplate engraving, it also serves to illustrate the identity of chemical and electro-dynamic action.

This process of electro-etching, it is stated by practical artists, is superior in several respects to the usual process of etching by nitric acid, both for copperplate and calico printing.

In order to insure uniformity of the electro-dynamic action on all parts of the plate to be etched, the receiving or negative plate should be arranged to present an equal proximity to the copper plate, as far as practicable.

Electro-embossing in Copperplate Engraving.

In describing *Electro-etching*, the transference of the particles of copper has been shown to take place from the portions of the copper plate, denuded of the non-conducting varnish, to the opposite surface of a conducting body, immersed near it in the acid. Supposing this receiving or negative conducting body to be a precisely similar plate of varnished copper, denuded of the non-conducting coating of varnish, to correspond with the positive plate, it is manifest that the particles of copper taken from cavities of the former will become transferred to fill up the furrows in the varnish, and to make protuberances, or embossed accumulations of particles of copper, adhering to the surface of the latter plate. By simply transposing the etched copper from its connection with the delivering pole to the receiving pole of the battery, we may not only fill up every furrowed line therein with fresh deposits of particles of copper, but may even accumulate particles into raised, projecting ridges, wherever there was previously a furrow. We have thus the command of an entirely new process of printing from the surface of the copper sheet, as from the surfaces of types, in the common mode of surface printing, instead of that of copperplate printing, which is effected by filling the chiselled furrows with ink, and wiping it clean off from the projecting surfaces. Thus, impressions from copperplate engravings may be obtained by the printer from the same form with common types, which cannot be done with regularly engraved copper plates, which require more expensive processes of labor of wiping off the ink, before subjecting them to the press.

This new process of preparing plates for surface printing has received the name of *Glycography*.

An improved mode of forming moulds, introduced by Mr. Palmer, has been termed by him, "*engraved drawings*." The artist operates on a composition of wax and resin, spread upon the surface of a copper plate, to the thickness of 1-30th of an inch. A copper cast is precipitated upon this mould, which is rendered stiff by being soldered to a thick plate, so as to form a perfect stereotype plate. The impressions taken from these plates appear exceedingly beautiful and spirited. As the artist has to operate only on a plastic wax, instead of hard wood, as in block engraving, this process promises to supersede, for some purposes, engravings on wood; particularly where the artist, who may not have the time or the ability to engrave on wood, can sketch directly on the plastic wax the designs he may wish to execute. Thus may be insured the spirited touches, which are often lost by the unskilfulness of ordinary engravers, in copying original sketches.

Cleaning Metallic Surfaces by means of Electricity.

As a coating of extraneous substances may be deposited by means of electricity on the surface of a metallic body, so may the same metallic surface be made clean by means of the galvanic battery, the article being attached by a wire to the copper, or negative pole, and plunged in an acid or saline solution. The decomposition of the water ensues, and the oxygen combines with the metal of the article to be cleaned, and the resulting oxide will be then dissolved by the acid or other solution employed. By this process, articles may be readily cleaned bright in a very few minutes. The acid solution employed should be selected with care, so as to apply one that will act only on the oxide or salt to be removed, and not on the metal of the article to be cleaned. For cleaning copper articles, a solution of sulphate of copper, slightly acidulated with sulphuric acid, may be employed; for silver surfaces, a solution of cyanide of potassium, or preferably of sulphite of potassa; and for cleaning iron articles, a saturated solution of sulphate of soda has been recommended by Mr. Spencer. A battery of three or more cells may be used for this purpose.

Detection of the presence of the Metallic Poisons by means of Electricity.

A series of experiments have been made by Mr. Edmund Davy, for the purpose of applying a current of galvanic electricity for the purpose of causing the precipitation of the salts of various metallic poisons, as a test of the presence of poisonous substances in cases of suspected poisoning. The electrical test is valuable as a means of analysis in such cases, for the result is not influenced by the presence of organic matter commingled with it in the contents of the stomach. For arsenic, or arsenious acid, "even when mixed with tea, coffee, sugar, rice, milk, starch, potatoes, gruel, eggs, bile, saliva, butter, lard, oils, &c., may almost immediately be precipitated by galvanic agency."

"When oily or fatty ingredients are combined with the metallic poisons under examination, the mixture is boiled in an alka line solution, and afterwards an excess of muriatic acid is added.

"In the detection by voltaic agency of the presence of metals, the most simple apparatus may be used: a small slip of zinc, and a similar slip of platinum, being in most cases all that is necessary. By means of this apparatus, the presence of gold, silver, mercury, copper, tin, lead, &c., may be almost instantly detected. If a drop of liquid, supposed to contain either of these metals, be laid on the end of the strip of platinum, and the slip of zinc be brought in contact at the same time with the liquid and platinum, if any metal be contained in the solution, it will be immediately reduced on the platinum.

"So delicate, indeed, is this method of reduction, that if only half a grain of arsenic be laid on the platinum foil, with two or three drops of muriatic acid, and touched, in the manner described, with zinc, that part of the platinum on which the liquid rests will immediately become coated with metallic arsenic, and filaments of the metal will become mixed with the liquid. On exposing the platinum to the heat of a spirit lamp, the metal is readily recognized by the garlic-like odor so peculiar to it."

"Metallic arsenic, thus reduced, may be obtained in the form of arsenious acid, by heating the platinum foil, on which it is reduced, in a tube loosely closed at the end. On applying the flame of a spirit lamp, the metal is volatalized, and condensed on a cool part of the tube in the ordinary form of arsenic."

By means of the preceding test, Mr. Davy states that the presence of only $\frac{1}{2500}$th part of a grain of arsenic may be discovered.

The preceding details will be sufficient to afford an idea of the discoveries recently made in this new branch of science, and of the important purposes to which it is destined to be applied in extending improvements in the ornamental, as well as in the useful arts. We stand on the verge of this yet unexplored ocean, as expressed by Newton, like children engaged in picking up curious shells and pebbles on the shore, ignorant of the secrets of the vast deep before them.

The practical operator will find in the works to which we have alluded, and particularly in Mr. Shaw's Treatise, an account of all the necessary precautions for insuring perfect success in the manipulatory processes.

To the artists who wish to become thoroughly conversant with all that has been published on the subject of transforming and depositing metallic coatings, are recommended the following volumes, which contain the minutest details of the practice of this new branch of the useful arts.

Galvano-plastic Art, by Professor Jacobi, in pamphlet form.

Smee's Treatise on Electro-Metallurgy, octavo volume.

Shaw's Manual of Electro-Metallurgy, a small octavo volume.

Familiar Instructions in Electro-gilding and Silvering, by William Sturgeon, in pamphlet form.

Fisher's Manipulations in the Scientifie Arts, in pamphlet form.

Electro Tint, or the Formation of Copper Plates and Blocks for Printing from Paintings, with Carbon on Metal Plates, by Thomas Sampson, in thin pamphlet form.

Electro-type Manipulations, by C. V. Walker, a small, cheap volume, *fourteen* editions of which have been published.

Davis's Manual of Magnetism.

ELECTRIC TELEGRAPHS.

PROPAGATION OF MECHANICAL IMPULSES THROUGH THE MEDIUM OF ELECTRICITY TO REMOTE DISTANCES, FOR THE PURPOSE OF TRANSMITTING COMMUNICATIONS BETWEEN INTELLIGENT BEINGS.

BETWEEN the tribunal of animal intelligence located in the organ of the brain, and the objects of the external world, as has been premised in treating of the Standard Tests of Physical Science (page 175), there are established radiating nerves, which serve as telegraphic wires for transmitting mechanical action through the medium of electric matter. When any of these nerves are cut off, as when telegraphic wires are severed, their powers of transmitting intelligence cease. The telegraphic wires, which are extended continuously to remote distances over hills and vales, represent simply an elongation of these nerves.

When, therefore, we find ourselves regarding with emotions of wonder the artificial employment of telegraphic wires and mechanisms to propagate electro-dynamic actions to remote distances, as a novel mode of transmitting intelligence, reflection teaches us that it is only an extension of a system naturally established within the mechanisms of all animal bodies.

The gradual progress of the invention of this artificial mode of extending the range of communication between mind and mind, will serve to prepare the way for the investigation of the concluding subject of Organic Action, which will terminate this inquiry into the causes and developments of Natural Motive Power.

Immediately after mankind were put in possession of the means of accumulating and controlling electrical power to an important extent by the discovery of the Leyden jar (page 372), experiments were commenced to test the extent to which this new discovery might be rendered available for developing sparks, shocks, and mechanical action between light, freely movable bodies, as recapitulated in treating of the nerves of Feeling and Sight, considered as electroscopic tests, and as represented by the movements of pith ball and gold-leaf electroscopes, figures 14 to 23. The movements of models of little mills were produced by electrical agency, and also the ringing of bells, and the revolving of wires, as represented at page 403.

In the year 1746 it is recorded that Winkler succeeded in transmitting discharges of Leyden jars through far-extended conducting wires; the river Pleiss having been substituted for a portion of the conducting wire of the returning circuit. The rapidity of the transmission of the discharges first led him to suggest the employment of electricity for telegraphic purposes.

Two years afterwards a similar experiment was repeated by Dr. Watson, near London, who caused electric sparks to appear simultaneously at the initial and terminal portion of an insulated conducting wire, four miles long.

In the year 1774 the first suggestion of the employment of electro-motive power developed by the divergency of electroscopic pith balls, was made by Lesage, in Switzerland. This suggestion was experimentally verified by Lomond, in France, in the year 1785. The former proposed using 24 sets of pith balls, each representing a letter of the alphabet; the latter used only one pair, varying the signals by the repetitions of divergencies, and by prolonging the time of their continuous divergency. This idea appears to have led the way to the use of dots and dashes (.) (—) made by the present plans of recording telegraphic alphabets.

About ten years afterwards Reizen exhibited a model of an electric telegraph, in which the letters of the alphabet were represented by the light of sparks across plates of glass of about an inch square. Strips of tin foil were pasted on the glass plates with intervals arranged so as to present to view the alphabetical letters. In an attempt to carry out this plan practically, a Spanish electrician, Belancourt, extended a circuit of wires 26 miles, between Aranguez and Madrid.

After Galvani's discovery of a new mode of exciting electricity, Soemering proposed having recourse to the appearance of air bubbles at the points of wires constituting prolonged circuits of galvanic batteries, each point being marked with a letter of the alphabet, visible at the bottom of a vessel containing transparent water, which was decomposed by electric action.

Dr. Coxe published in Thomson's Annals of Philosophy in 1816, a suggestion of the employment of electricity for telegraphic signals, by using "tubes for the decomposition of water and of metallic salts, regularly arranged."

In the same year Mr. Ronalds insulated 8 miles of wire on posts, as is now practically accomplished. He attempted to make intelligible signals by means of two clocks beating time together, and with a pair of pith balls suspended near the second-hand, each mark of a second having a letter of the alphabet or numeral figure affixed to it upon the dial-plate.

Schweigger having invented the galvanoscope soon after Oersted's discovery of the deflection of a magnetic needle by means of a conducting wire, Ampère suggested using as many needles as there are letters of the alphabet, each connected with a distinct circuit of conducting wires. He suggested that these several circuits "might be made to communicate with the galvanic battery by means of keys, which might be pressed down at pleasure, thus allowing scope for a telegraphic correspondence that might be transmitted instantaneously to any distance, as intelligibly as writing or speech."

The following extract from the Spectator, No. 231, written one hundred and forty years ago by the classic pen of Addison, and repeated in the Guardian, No. 119, will serve to show that there is scarcely an invention which is strictly novel in the conception, or which has not been anticipated in the dreamy visions of imaginative men. And this extract refers back to a writer antecedent to the days of Addison.

"Strada, in the person of Lucretius, gives an account of a chimerical correspondence between two friends by the help of a certain loadstone, which had such a virtue in it, that if it touched two several needles, one of the needles so touched began to move; the other, though at never so great a distance, moved at the same time, and in the same manner. He tells us, that two friends, being each possessed of one of these needles, made a kind of dial-plate, inscribing it with the four-and-twenty letters, in the same manner as the hours of the day are marked upon the ordinary dial-plate."

"Then they fixed one of the needles on each of these plates in such a manner that it could move around without impediment, so as to touch any of the four-and-twenty letters. Upon these separating from one another into distant countries, they agreed to withdraw themselves punctually into their closets at a certain hour of the day, and to converse with one another by means of this their invention. Accordingly, when they were some hundred miles asunder, each of them shut himself up in his closet at the time appointed, and immediately cast his eyes upon his dial-plate. If he had a mind to write any thing to his friend, he directed his needle to every letter that formed the words which he had occasion for, making a little pause at the end of every word and sentence to avoid confusion. The friend, in the mean while, saw his own sympathetic needle moving of itself to every letter, which that of his correspondent pointed out. By this means they talked together across a whole continent, and conveyed their thoughts to one another in an instant over cities and mountains," &c.

It will be presently seen how nearly these visionary anticipations of what once was doubtlessly deemed a flighty imagination, have been realized by the electro-magnetic telegraphs recently put into actual operation by Cook and Wheatstone. Had Addison suggested the use of a conducting wire in his theoretical anticipations, his supposititious account might have been deemed at the present time a veritable description of the principles of Wheatstone's Electric Telegraph, as at present in use in England.

Similar observations of the energetic mechanical action developed by combustion, or fire, once attracted the notice of a sacred writer, to whose fancy this energetic action was forthshadowed in the following verse: "The chariots shall seem like torches, they shall run like the lightnings."—Nahum, 2 ch., 4 v.

Notwithstanding the apparent simplicity of Ampère's proposed plan of transmitting electro-telegraphic signals, yet so frequent and delusive had been all the previous projects for rendering available the rapid propagation of electric action to remote distances, for transmitting telegraphic signals, that it appears to have attracted but little notice during a period of several subsequent years.

The first recording electro-chemical telegraph appears to have been constructed by Mr. Dyer of Long Island, New-York, in 1826. He employed electric sparks to act upon a fillet of moistened litmus paper, drawn forward by hand or clockwork beneath the point of a wire. Each spark, on penetrating through the paper, left a stain or spot, corresponding with the dots since used in the alphabets adopted by Morse and Bain.

In 1828, Tribouillet revived the notion of the adoption of the motive power of electricity applied to producing the divergent movement of the pith balls of electroscopes; and in the subsequent year, Fechner, in his publication of a "Manual of Galvanism," recommended that Ampère's suggestion should be tested between Leipsic and Dresden, by extending 24 lines of wires having 24 galvanometers connected therewith. Inspired with the idea of the successful results of such an experiment, he boldly prophesied, that probably hereafter, there may be brought about such an instantaneous transmission of intelligence between the centre and extremities of a kingdom, as exists between the central point and the distant members of the organic structures of living beings.

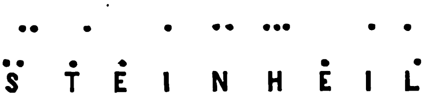
The experimenters were all doubtlessly deterred from pursuing attempts to carry out the plans suggested of employing galvanic batteries to propagate electric action to a distance, from the fact of the rapid diminution of the power transmitted through long wires. Mr. Barlow, the eminent author of a treatise on Magnetism, affirmed his belief, from the sensible diminution of electro-motive power at the end of a wire only 200 feet long, that it would be impracticable to employ galvanic electricity for telegraphic purposes. And Professor Daniel remarked that "Electro-magnets of the greatest power, even when the most energetic batteries are employed, utterly cease to act when they are connected by considerable lengths of wire with the battery."

The fact of the propagation of the power of a galvanic battery to a distance of nearly a mile, with a sufficient energy to turn a magnetic needle on its point, was tested in Goetingen by Gauss and by Weber, in the year 1832. Even a minute pair of plates of an inch square was found adequate to affecting the Galvanometro needle; and a magneto-electric machine was also found by them to produce deflections of the needle. To avoid the complexity of numerous circuits of wires consequent on the employment of twenty-four needles to represent the letters of the alphabet, as suggested by Ampère, they used only one needle and one circuit, the circuit being reversed to make distinctions between the signals. The movements of the needle to one side, and then to the opposite side, combined with pauses between repetitions of such movements, served to establish an intelligible telegraphic alphabet.

Professor Steinheil next brought forward the plan of an electro-magnetic telegraph, to be operated like the preceding one, with a single circuit of wires, terminated in a helix-coil, encircling two heavy magnetic needles, one above the other. By reversing the direction of the current, he could thus cause the pole of either the upper or lower needle, at pleasure, to swing against a fillet of paper, drawn along near the sides of the two poles, by means of a weight operating on clockwork. A pencil was first used to make dotted marks on the paper; but the power of the needles being feeble, he subsequently used a small tube, filled with printer's ink, which, without running out, formed a projecting, semi-globular protuberance, admirably adapted to making dots.

By means of these two needles, he could make two lines of dots, as represented in the figure. He thus produced, in 1837, the first MECHANICAL RECORDING TELEGRAPH.*

Fig. 165.



Numerous competitors now speedily entered the field, with zealous rivalry to secure emolument and pre-eminence. Schilling, Masson, Taquin, and Ettiehausen, took the lead on the continent of Europe; Alexander, Cook and Wheatstone, E. Davy, and Bain, in Great Britain; and Morse in the United States.

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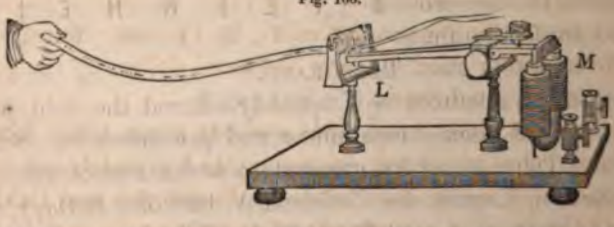
* Annals of Electricity, 1839.

In Great Britain, Alexander first entered a claim for a patent in 1837, on the plan, suggested by Ampère, of employing a number of magnetic needles, each representing a letter of the alphabet. Two months afterwards, Cook and Wheatstone entered a similar claim for the improvement of using only five circuits of conducting wires, instead of thirty circuits, as specified by Alexander. They succeeded in putting their plan into operation near London. On the 12th June, 1840, Wheatstone obtained letters patent for his improvements in electric telegraphs in the United States, and eight days afterwards similar letters patent were granted to Professor Morse, although a caveat had been filed by him several years previously.

Morse's plan differs from those adopted in Europe, by employing a bar of soft iron, environed by a helix-coil (page 247, fig. 42), instead of magnetic needles. The surprising discovery of the great power of electro-magnets, adequate to supporting the weight of a ton, made by Professor Henry in 1832, (pages 513 and 516), having attracted universal attention to this new mode of developing extraordinary electric action, the possibility of propagating a galvanic current to excite electro-magnets by conducting wires extended many miles in length, remained to be verified experimentally, as appears by Professor Morse's statement.*

"At an early stage of my experiments, I found that the magnetic power, produced in an electro-magnet by a single galvanic pair, diminished rapidly as the length of the conductors increased. I did not feel entirely assured that magnetism could be produced by a multiplication of pairs, sufficiently powerful, at a great distance, to effect my purpose."

Fig. 166.



This purpose was to extend the action of a galvanic current through a conducting wire trained to some place at a remote distance, for the purpose of converting a piece of soft iron into an electro-magnet, (fig. 42, page 247.) By causing a current to circulate about a wire, wound in numerous spiral coils about a piece of soft iron, bended to the form of an U, and arranged as at M, it may be converted, at pleasure, into a magnet, and caused to cease exerting magnetic action, simply by breaking the connection of the conducting wire with the battery. A piece of iron is represented in the figure suspended about 1-8th of an inch above the poles of this U magnet, at the end of the movable lever L.

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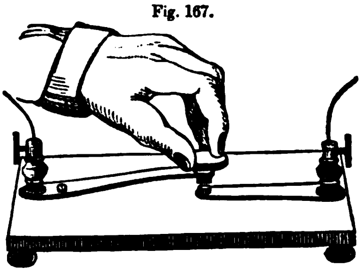
* Vail's American Telegraph, page 92.

When the current is transmitted about M, this cross-piece of iron is drawn down upon the two poles beneath it, simultaneously tilting up the opposite end of the lever L, against a strip of paper, which is continuously drawn forward above a pencil, or steel prong, inserted in the end of the lever.

To accomplish readily the process of establishing and breaking contact of the conducting wires of the battery circuit, a spring was arranged to be pressed down upon a plate, as represented in the figure.

Fig. 167.



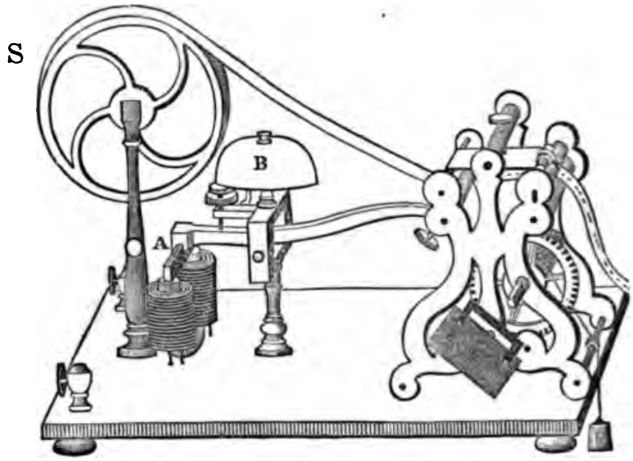
In September, 1837, Professor Morse made his first successful experiment, with one-third of a mile in length of a conducting wire. It now only remained to test experimentally the practicability of propagating the electro-motive power from a galvanic battery, through a long line of many miles of telegraphic wire, to act upon an electro-magnet.

The principal details of these experiments have been narrated in treating of the conduction of galvanic electricity (pages 395 to 397), as was finally accomplished, by Professor Morse, by the aid of an appropriation of thirty thousand dollars by the government of the United States.

It was not until April, 1844,—about seven years after the first experiment exhibited,—that the plan was finally put in practical operation, on the line between Washington and Baltimore, where I then had an opportunity of examining the mechanism in operation.

In the annexed cut is represented the complete arrangement of the mechanism of Morse's Telegraph. The electro-magnet, wit the iron cross-bar above its poles, is shown at A. The fillet o paper is drawn off the spool S by the rollers, moved by a weigh operating the clockwork. At the instant the lever is draw down by the electro-magnet, a detent is disengaged, and the pape is gradually moved forward above the vibrating point, attache to the end of the lever. This point may, at pleasure, be cause to make a dot or prolonged mark on the paper, accordingly as th contact with the battery circuit is abbreviated or prolonged.

Fig. 168.



The first movement of the lever is caused, also, to detach another detent connecting the clockwork with the hammer of th bell B, which is designed to communicate audible signals, t arouse the attention of the attendant. But the bell is now commonly dispensed with, as the noise made by the chattering of th movable parts of the instrument, on establishing and breakin rapidly the battery circuit, is sufficient to attract the notice of th attendant.

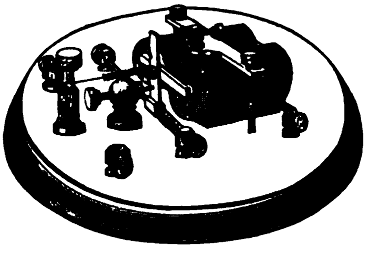
The intensity of the mechanical action, propagated from combination of 50 pairs of Grove's battery, was found by Pr fessor Morse, in his early experiments, to become diminished fro a power adequate to suspending from the armature 9 ounces, the termination of 2 miles of wire, to a power adequate to su pending only 1-8th of an ounce, at the termination of 33 mile

With this feeble power, a slight mechanical action only could be developed in marking paper with the point of the wire.

To remedy the difficulty of this slight power, the primary battery has been employed merely to establish contact between the poles of a fresh battery, arranged near the apparatus, at the distant station. These fresh batteries have been denominated *Relay Batteries*, in allusion to the employment of relays of fresh horses on post routes.

The *relay* battery, stationed by the side of the telegraphic apparatus, is put into action, and thrown out of action, by the operator with his battery at some distant station. In this case, it is only necessary to employ sufficient electro-motive power to move a very delicate, freely-movable armature and lever, or to swing a magnetic needle around, so as to break and renew the circuit of this *relay* battery.

Fig. 169.



The apparatus of a *Relay Battery* is represented in the figure. By extending this combination of a succession of relay batteries, the electro-motive power may be propagated to any distance to which such an arrangement of local batteries can be practically extended,—even were it about the entire circuit of the earth.

The original introduction of this plan was effected by Professor Henry, in the year 1836, at Princeton, whereby he was enabled to cause large bells to be rung at a distance.

It is stated by Mr. Walker, that the relay batteries may be dispensed with by simply increasing the number of pairs, and by distributing them at regular distances along the line. He remarks,* " We have made abundant experiments on the line from Philadelphia to Louisville, a distance in the air of *nine hundred* miles, and in circuit of *eighteen hundred* miles. The performance of this long line was better than that of any of the shorter lines; and " the same success attends the work from Philadelphia to St. Louis, A DISTANCE IN CIRCUIT OF ONE-TWELFTH OF THE EARTH'S CIRCUMFERENCE."

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* American Journal of Science, March, 1849.

"The number of Grove's pint cups used is about one for every twenty miles. It is natural to conclude from this experiment, that if a telegraph line around the earth were practicable, twelve hundred of Grove's pint cups, in equidistant groups of fifties, would suffice for the galvanic power of the whole line." "The daily expense of acids for maintaining the whole line would be about four mills per day for each cup, or six dollars per day for the whole line."

Among the earliest experimental attempts, it has been narrated, the earth was employed for the returning portion of the circuit. This plan is now practically adopted; and only one leading wire is requisite for telegraphic circuits.

The following is the combination of dots and lines on the fillet of paper used by Professor Morse, to indicate the different letters and numbers:—

Morse's Telegraphic Alphabet.

ALPHABET.

a ·—
b —···
c ·· ·
d —··
e ·
f ·—·
g ——·
h ····
i ··
j —·—·
k —·—
l ——
m — —
n —·
o · ·
p ·····
q ··—·
r · ··
s ···
t —
u ··—
v ···—
w ·——
x ·—··
y ·· ··
z ··· ·
& · ···

NUMERALS.

1 ·——·
2 ··—··
3 ···—·
4 ····—
5 ———
6 ······
7 ——··
8 —····
9 —··—
0 ———

Between each letter of a word a short space is allowed; between words, a longer space; and between sentences a still longer one. Many short hand signals are also employed.

A most elaborate plan of effecting electro-telegraphic communications was patented in England, in July, 1838, by E. Davy, the description of which occupies twenty pages of the Repertory of Patent Inventions, with numerous appended drawings.* His claims to originality of invention consist "in the employment of chemically prepared fabrics for receiving marks by the action of electric currents," and in reinforcing the electric power at remote stations by *Relay Batteries*, successively brought into action by the agency of the original battery used by the operator, including the branching off from the main line of wires of any number of wires extended to collateral stations.

Not satisfied with the use of a pointed wire to mark dots and dashes on paper, ingenious experimenters have contrived to put in operation the mechanism of clockwork operated by weights, to move a wheel, having types of the twenty-four letters of the alphabet arranged on the rim, so as actually to *print the letters of the telegraphic communications* in a legible form on the paper.

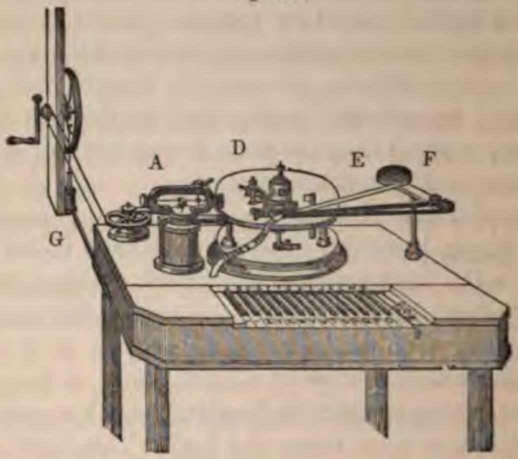
In these attempts, Bain, in England, and Vail and House in the United States, have taken the lead. The latter appears to have been successful in putting into practical operation a regular Printing Electric Telegraph, which is now daily viewed by astonished visitors as one of the greatest wonders of this age of inventions.

House's Printing Telegraph.—The working parts of this instrument require to be examined in order to comprehend, clearly, the details of their arrangements. A perspective view of the machine is represented in the wood-cut, with the vertical iron bar electro-magnet A, inclosed in a tube of brass, within which are several short tubes of iron. In front are 28 keys resembling those of a piano-forte, each one having a definite letter assigned to it, corresponding to a type of the same letter in the type-wheel, with two punctuation marks. The end of the printing lever, or press, is shown at D, and the fillet of paper at E, which is drawn off regularly from the roll at F, passing between the face of the type-wheel and an endless band well blackened with ink. One revolution of the arm brings the press, ink-band, and

* New Series, vol. xii.

paper quickly together against the type, and as quickly withdraws them. The paper is then drawn forward by a ratchet, and is ready to receive another impression.

Fig. 170.



The machinery of the printing press and of a forcing syringe for injecting air, is represented at G, and is all worked by the crank handle by manual power, or by weights.

The motive power of the voltaic current is only employed to give motion to an air valve, which governs the vibrations of the type cylinder. *The principle of the operation of this machine is based on the propagation of a certain specific number of impulses of mechanical force, through the medium of electricity, to bring forward* each type. This is effected by the rapid opening and closing of the battery circuit a specific number of times for each letter of the alphabet. The type-wheel is caused to revolve by the manual power applied to the crank handle, and a constant pressure of condensed air is also sustained to operate alternately on the opposite sides of a piston, in an air-tight cylinder, causing it to vibrate like a piston in the cylinder of a steam engine. The electro-motive power, therefore, simply performs the function of opening and closing the air valves, whilst the power is propagated from the compressed air to the piston, to one end of which an escapement is attached, the office of which is to release the type-wheel, and to let type after type pass by it successively, until the specific number of vibrations have been completed, which the operator may cause to take place on touching any one of the alphabetical keys.

The electric circuits connected with the several keys are rapidly broken and restored by a metallic point touching successively the teeth of a revolving-wheel, whose circumference is divided into twenty-eight equal parts, 14 teeth, or cogs, and 14 spaces between them. The shaft to which this wheel is attached contains also a spiral row of 28 teeth, which bring up against pins or stops projecting from each of the several keys. These arrest the type-wheel with the desired type fronting the paper to be printed thereby.

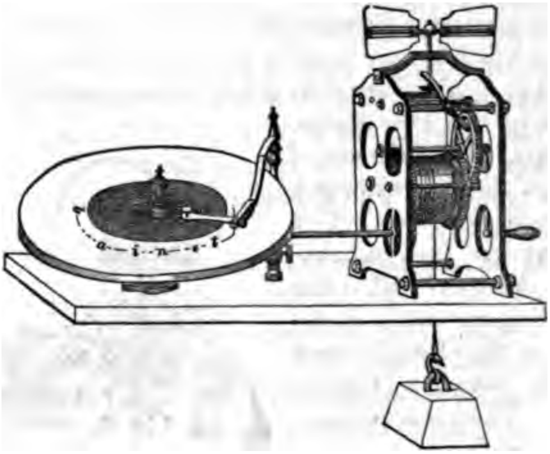
It is to be remembered that another apparatus of this same kind is stationed at the other remote station or extremity of the telegraphic wire. They are alternately used to transmit and to receive communications. If the instruments at both ends of the line be set to the same letter, then the cylinder at one extremity, and the type-wheel at the other, regulated by the number of pulsations of the current, will keep pace with each other in a step by step movement, and stop with the same type presented in front of the paper, to be printed thereby.

By this truly wonder-working mechanism, Roman letters are successively printed on a strip of paper at the rate of from one hundred and fifty to over two hundred per minute.

Bain's Electro-Chemical Telegraph.—A more simple and efficient plan of electric telegraphs than the preceding ones, based on *electro-mechanical* action, appears to be accomplished by means of *electro-chemical* action. The plan, previously adverted to, as suggested by Dyer and Davy, has been successfully put into operation by Mr. Bain. It is not necessary, in the operation of the electro-chemical telegraph, to propagate impulses through the medium of electricity in the form of mechanical action. The simple passage of a spark is sufficient to produce electro-chemical polarizations, as has been explained at page 553.

The plan of Bain's apparatus is exhibited in the cut. The end of the connecting wire constitutes the pen; it remains stationary, and is caused to press steadily upon the surface of a circular metallic plate, which is kept slowly revolving with the paper upon it, by a weight acting on clockwork. The electric sparks pass through the chemically-prepared paper from the point of the wire to the surface of the plate.

Fig. 171.



The paper is moistened with a solution of cyanide of potassium, or common yellow prussiate of potash, acidulated with muriatic or sulphuric acid. It is well known that Prussian blue is composed of the prussiate of potash and iron. The particles of th point of the wire, composed of the latter metal, are caused by th electric action to become chemically combined with the moistene solution with which the paper is impregnated, and to form permanent deep blue stain or spot.

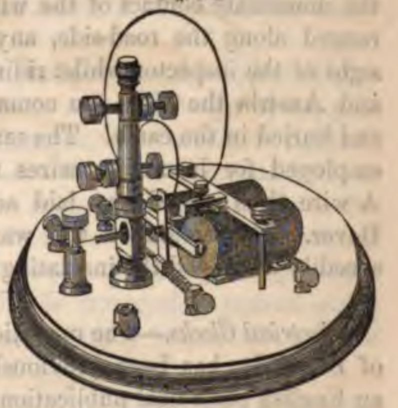
The spectator, who watches the operation, perceives the whit paper to approach the point of the wire, and then to recede froi beneath it with a succession of dark dots and dashes, produce by the intermitted current, controlled by the distant operator.

If the point of the wire were to remain at the same distanc from the centre of the revolving plate, it is manifest that th marks would be repeated over again on the same lines. To pr vent this, the point is connected with a guide following a spir groove cut in the centre of the plate, as represented in the figur By this admirably simple contrivance, the lines of dots an dashes, constituting the alphabetical characters, are traced i spiral circles, one within another, thus occupying but little space, and dispensing with the use of long fillets of paper.

So readily propagated through distances of several hundred miles of telegraphic wires is the electro-chemical or electro-polarizing power, that *relay batteries* are not so frequently requisite as in the electro-mechanical telegraphs.

As this apparatus works so silently as not to arrest the notice of the attendant by any audible sounds, two circular plates of bell-metal or of glass, are arranged, as represented in the cut, to be struck by two little knobs, or hammers. The difference of the sizes of the plates causes a difference of the tones. This instrument has been denominated an *Electrical Call*. The reciprocating movement of the armature of the electro magnet causes the hammers to strike the glass. The transmission of audible sounds as a mode of transmission of electro-telegraphic communications, has been described at page 390.

Fig. 172.



Mr. Bakewell has obtained a patent in England for propagating telegraphic communications, by which in some degree the very chirography of the correspondent is copied. This is accomplished by writing the communication on a varnished plate of metal, and by arranging the point of the connecting wire by machinery to traverse back and forth over the plate. Where the metal is bared of varnish, the point touches the metal, and establishes the circuit.

So rapidly has this new application of science become extended throughout the United States, that it now constitutes a very considerable branch of business. The aggregate amounts paid for telegraphing probably now exceed a million of dollars per year.

Insulation of Telegraphic Wires.—Tall poles were used by Steinheil in his first experiments of insulating telegraphic wires, a piece of felt being applied at the point of contact of the wire with the wood. To prevent the interruption of the use of the wires by mischievous persons, Cooke and Wheatstone incurred very heavy expenses by coating the wires with non-conducting substances, and by inclosing them in iron tubes, laid between London and Windsor. Mr. Morse, in the United States, embarrassed his early experiments by costly expenditures for carrying out the same plan.

This plan failed from imperfections in the insulation. Posts have been found to be most advantageous, with glass to receive the immediate contact of the wires. These posts being usually ranged along the road-side, any fault of insulation is in plain sight of the inspector whilst riding along the road. In Germany and Austria the wires are commonly coated with gutta percha, and buried in the earth. The same material has been commonly employed for insulating wires used for submarine explosions. A wire thus coated was laid across the British Channel from Dover. The action of the waves near the shore, however, speedily destroyed the insulating coating.

Electrical Clocks.—The operation of electrical clocks by means of *Dry Piles*, has been previously described at page 337. In an English periodical publication it has been stated that "in the tower of a church near Ipswich, an Electrical Clock is kept in incessant motion by the motive-power derived from plates of metal buried in the earth."

The following account of an Electrical Clock, in the Telegraph Office in London, will afford interesting information of the actual advancement made in this branch of electro-dynamic science.

"This clock was originally invented and patented by Mr. Bain, but is now the property of the Electric Telegraph Company. The pendulum, which in ordinary clocks merely serves to equalize the motion of the escapement, is here acted upon directly by the moving power. Instead of the wheels of the clock imparting motion to the pendulum, the pendulum imparts motion to them, derived from the joint action of electricity and magnetism."

"The exciting battery is composed of a sheet of zinc sunk into the moist earth, with a bed of pulverized coke beneath it, and also laid thereon; copper wires are connected severally with the two beds of coke. The wire and zinc plate form one pole of the battery; the coke, with the connecting wire, the other. Wires attached to each of these poles are connected with the clock by a pair of brass brackets inserted in the back of the clock-case, about half way down the rod of the pendulum. In one bracket is a small surface of gold, and in the other a small pin of the same metal, inserted in the centre of a slab of agate. Upon these brackets rests a movable steel slide; which, at every vibration of the pendulum, is moved from side to side by a pin inserted in the pendulum rod, that moves it forward in the direction of each swing."

"When the slide touches the pin, the electric current is conducted through it; and when it is withdrawn therefrom, and left resting on the non-conducting agate, the current is shut off. Whilst the current passes, it is conveyed by means of another wire to the top of the pendulum, from which it descends to the lower end or bob; which is hollow, and within which are arranged 800 yards of fine coated wire in the form of a helix-coil. The returning circuit of the wire is arranged to ascend along the pendulum rod to the top, and is thence led off to complete the contact with the other pole of the battery."

"The coil of copper wire of the bob of the pendulum faces the ends of two permanent steel magnets, the N poles of each of which are turned toward the coil.* Whilst the steel slide is in contact with the gold pin, the current circulates about the coil, imparting to one side of it the property of the north pole of a magnet, and to the other the property of the south pole of a magnet.† As two similar north poles of magnets always repel each other and two dissimilar poles always attract each other, the coil of the pendulum is urged *from* the N pole of the magnet on one side, and *toward* the N pole of the magnet on the other side."

In this swing, the pendulum pushes along the steel slide of the gold connecting pin, upon the non-conducting agate. This of course interrupts the further circulation of the electric current about the coil, which instantaneously loses its magnetic properties. Then the pendulum makes its return swing by the force gravitation. In so doing, however, it again pushes the steel slid into contact with the gold pin, whereby the current is restored and the same operation is repeated continuously: and it mu go on, so long as the plate of zinc remains undecomposed in th earth.*

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* The principle of this arrangement is exhibited by figure 87, page 243.

† Page 241, figure 86.

"It may be mentioned in connection with this electric cloc that the Telegraph company are making arrangements for con municating the true time, as daily noted at the Royal Observ tory at Greenwich, to every station on the various lines, whe the company have telegraphic stations in all the large tow throughout the kingdom. We believe it is now the daily pra tice at Greenwich, at meridian, to indicate the true time by dro ping a ball from the upper part of the observatory; which bein telegraphed to the admiralty, and by signals to the shipping i the Thames, enables the shipmasters to adjust their chronom ters. It is intended that the ball on being detached and con mencing to fall, shall touch a spring, which may extend t electric action instantaneously to strike a bell at every telegr phic station, as at Manchester or Liverpool, before the ball sha have reached the ground."

By connecting the pendulums of clocks at several remo stations with the same battery circuit, they may be caused beat seconds at the same instant of time, or to be really synchr nous in their indications of the measures of the lapse of tim Several clocks were thus regulated on the telegraphic line alo one of the London railways to keep perfect time together. T sounds of the clicking of the keeper against the poles of the el tro-magnet so nearly resemble the regular clicking of the clo at a distant station, that the observer may readily imagine it be at his side.

The subdivision of time of one second of duration is not s ficiently minute for nice astronomical observations; for in th interval of time, between the successive beats of a second-pe dulum, the surface of the earth in the latitude of Washingto moves in its rotation on its axis through the space of about o quarter of a mile; and unless there be means of dividing the i terval between the beats of the pendulum into distinct recognizable subdivisions, it is manifest that astronomical clocks could afford only approximative results within about $\frac{1}{4}$th of a mile, and that an exact accuracy could not be obtained in determining the longitude of places by the observation of the times of transit of the planets Mercury or Venus over the disk of the sun. But with the capability of signalizing within one-tenth part of a second of time, it is manifest that the accuracy of locality on the earth's surface becomes reduced to $\frac{1}{10}$th part of $\frac{1}{4}$th of a mile, or about 130 feet; so that it might be discoverable, by means of observations of the transit of Mercury or Venus, whether the instruments for observation be placed at the east or west end of a building or room.

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* By arranging the mechanism of a "current-changer" in connection with t pendulum, a doubly effective electro-motive power would be developed.

To insure accuracy of observations, it appears that Mr. Mitchell, of the Observatory in Cincinnati, turned his attention to this subject; and constructed the first mechanism actually used for the purpose of denoting subdivisions of a second as denoted by the electro-telegraphic action on an astronomical clock. Dr. Locke, of the same city, has published in Silliman's Journal, October 1849, an account of the mechanism for denoting subdivisions of a second by electrical agency.

These brief illustrations of the propagation of impulses originating from solar excitation, through the medium of electricity, between atoms and masses of *lifeless* matter, must terminate our investigations of the subject of INORGANIC ACTION. It remains now to trace out the propagation of mechanical impulses through the medium of electricity between atoms and masses of *living* matter, constituting the last classification of ORGANIC ACTION and of ANIMAL MOTIVE-POWER.

DYNAMICS.

ORGANIC ACTION, OR, THE PROPAGATION OF SOLAR ACTION, MODIFIED BY ORGANS OF PLANTS AND ANIMALS.

Organic Action produces reciprocal movements of matter in every *relative direction* (page 170). Inorganic Action produces movements in only *three specific directions*; viz., *toward*, *from*, and *about* each other's centres.

All the movements of matter produced by Inorganic Action have been shown in the preceding pages to be traceable to mechanical impulses propagated through the medium of electric matter in *similar*, *dissimilar*, and *transverse* directions (fig. 34, page 214). The movements of atoms and masses by Organic Action, have been shown to be produced by the propagation of the electro-dynamic action of the sun variously modified by the mechanisms of the organs of plants.

Although in external symmetry of equal corresponding sides and angles, Inorganic Formations may resemble Organic Formations, as represented by the comparative similarity of the external shapes of the groupings of atoms into crystals, and into the bodies of plants and animals (page 88), yet the arrangement of the groupings, and the kinds of constituent atoms, combined in their *internal* structures, have not the least analogy to each other. The crystals may be produced, decomposed, and reproduced, at the pleasure of the experimenter, simply by modifying the propagation of mechanical action, through the medium of electricity, in opposite directions, by means of the employment of a galvanic apparatus. But it requires the employment of the power of modifying the propagation of the electro-dynamic action of the sun, *innate* in the groupings of atoms in the germ of a plant, to reproduce a similar grouping of atoms into another germ, as has been detailed at pages 98 and 99.

Mankind may produce the Inorganic formation of a symmetrical crystal by the use of an artificial galvanic apparatus, as has been detailed in treating of electro-metallurgy; but if it is desired to produce any kind of Organic formation of a plant, recourse must necessarily be had to the organs of a germ of that particular plant, as a specific natural galvanic apparatus, expressly designed to become excited by solar action, and to reproduce a similar apparatus.

The artificial apparatus of a galvanic battery may be employed at the pleasure of the experimenter to develope Inorganic reactions for the purpose of producing static conditions of groupings of atoms into crystals, and of propagating dynamic impulses through the medium of electricity, in the various forms of Heat, Light, Chemical Action, &c. But no artificial apparatus can be employed to develope Organic action capable of producing groupings of atoms into plants or animals. In the words of Scripture, "Who, by taking thought, can add one cubit to his stature?" It is beyond the power of man to produce a grouping of atoms which will even serve as a substitute for the Organic formation of FOOD, as recapitulated at page 161.

Hence the conclusion is unavoidable, that all the natural kinds of electro-dynamic apparatus of vegetable and animal bodies are the absolute determinations of the will of a superior Intelligence and Power.

Considering, then, all organic formations to be really mechanisms created by an infinitely intelligent Power, it becomes an interesting and instructive study to trace out the plans of construction and operation of these mechanisms, and the modes in which they are calculated, severally, to propagate mechanical impulses through the medium of electricity, in the specific form of ORGANIC ACTION.

With a prescience of effects of organic formations producible by solar action on the germs of plants, a child may plant an acorn on a sunny hill-side, and witness the development of the germ of the oak, on each returning summer sun. During his allotted three score and ten years, he may behold circle after circle of woody fibre embodied in the trunk, and rambling branch after branch to become extended in the air. With vigorous juvenility this oak will flourish when the child has become a feeble old man. Successive generations in boyhood may sport beneath its broad branches, and "wither away like the grass which they tread:" and still the oak will continue vigorous. Cycles of centuries may finally pass away before it becomes a hoary tree, mossy with age, and yields up to the control of Inorganic reaction its decaying branches.

To account for this long continuance of vitality in an oak,—of the paramount supremacy of its Organic action over Inorganic reaction, no mechanical explanation admits of being offered. Nor can the mystery be unfolded by mechanical laws, why the Organic action should continue during unequal periods in the race of man and in that of oaks; or why the moss which clings to its bark, and the insect of an hour that feasts upon the moss, should not be endued with equal longevity. It is enough for intellectual man to recognize the fact, and to bow in acquiescence to the inscrutable laws which have ordained an inevitable destiny.

Observations of these laws teach us that in the vernal season, the Organic action of vitality prevails over the Inorganic reaction; and that at another, the Inorganic reaction in turn becomes paramount. These facts have all been reviewed in treating of the germination of plants,—of seed-time and harvest—of the organic formation of food and fuel, and of their recoil by the processes of combustion, fermentation, and putrefaction, to their natural static conditions of water and carbonic acid gas.

The diametrically opposite and specific designs of the construction and operation of the distinct mechanisms of vegetable and animal bodies, have also been illustrated at page 141, in the table exhibiting the antagonistical forces and functions developed by the oppositely directed impulses of electro-dynamic action, as variously modified by the organs of plants and of animals.

Vegetable Organic Formations have been shown to be mechanisms scientifically devised for accomplishing the specific purposes of serving to modify the propagation of the electro-dynamic action of the sun in grouping together about half a dozen different kinds of elementary atoms in constrained static conditions of fruits, seeds, grains, and grasses, constituting FOOD; and of wood, peat, &c., constituting FUEL.

Animal Organic Formations have been shown to be mechanisms constituted of groupings of atoms of vegetable organic formations constituting food, which have been assimilated and regrouped by animal organs. The vegetable kingdom, it has been shown, serves to purvey for the animal kingdom, as the jackal is fabled to purvey for the lion.

It appears by the Mosaic account of the creation, that the original excitation of organic action and animal motive-power in man was first produced by the process of "breathing into his nostrils the breath of life."

Had this account been written in modern scientific language, the original excitation of animal motive-power would have been ascribed to the process of the inflation of the lungs with the oxygen of the air to produce the chemical decomposition of the blood circulating therein, by restoring it to carbonic acid gas and water.

Chemical, mechanical, and hierographical sciences conspire in ascribing the origin of animal motive-power to the decomposition of the blood in the lungs by the process of breathing. It has been shown (page 152), that blood is constituted of the organic formations of the plants, which were originally ordained to be the "meat" or food of animals.

Human powers of perception are too feebly constituted for ascertaining, by direct observations, the mode in which energetic impulses of mechanical force are developed during the successive contacts and unions of atoms of oxygen with metals in the galvanic trough; or of the same kinds of atoms of oxygen with those of carbon in the furnace of a locomotive engine. They are in like manner inadequate to ascertaining by direct observation how the recoil of the groupings of elementary atoms of food, within the lungs of animals, can produce the development of ANIMAL MOTIVE-POWER. It remains, therefore, to trace out by analogy the originating mechanical cause of the development of Organic Action in the form of Animal Motive-Power.

ANIMAL MOTIVE-POWER TRACEABLE TO THE RECOILING INORGANIC REACTION DEVELOPED DURING THE COMBUSTION, IN THE LUNGS, OF FOOD PRODUCED BY THE ELECTRO-DYNAMIC ACTION OF THE SUN.

In treating of Animal Organic Formations, it has been shown in the Table at page 141, that ANTAGONISTIC FORCES and FUNCTIONS are developed by the oppositely modified propagation of solar action through the mechanisms of the organs of Plants, and of Animals.

A plant constitutes a mechanism manifestly designed to be operated upon like a thermo-electric apparatus immediately excited by solar rays, to produce groupings of atoms into FOOD and FUEL. An animal, on the contrary, constitutes a mechanism like the same thermo-electric apparatus excited indirectly by the combustion of this fuel (figure 83, page 342). Nearly all the *food* taken into the stomachs of animals is burnt in the lungs (page 145), to sustain the continuous excitation of this mechanism.

A vigorous man breathes forth from his lungs each day a volume of carbonic acid gas, which by analysis is found to contain about 13 ounces of pure carbon. This quantity of carbon is equivalent to an equal weight of pure charcoal, burnt daily in his lungs, to develope the electro-dynamic excitation constituting *animal heat* and *animal motive-power*.

The process of *digestion* in the stomachs of animals (page 151), is the dissolving of groupings of atoms of food into the fluid animal organic formation of BLOOD.

By exposing dried blood in a covered crucible to a red heat (page 146), there is found a residuary quantity of charcoal which cannot be distinguished from the charcoal left in the same crucible after wood, bread, sugar, flesh, &c., have been similarly experimented upon.

In the chapter on the process of Combustion, it has been repeatedly noticed that the atoms of carbon and hydrogen recoil from their groupings of organic formations to the aeriform state of carbonic acid gas and water. By analyzing these products of combustion, it is found that the atoms of carbon have become grouped with those of oxygen in the ratio of $\frac{6}{22}$ parts of the former to $\frac{16}{22}$ parts by weight of oxygen, to form carbonic acid gas; and that the atoms of hydrogen become similarly united with those of oxygen in the ratio of $\frac{1}{9}$ of hydrogen to $\frac{8}{9}$ parts of oxygen, to constitute water. In this ratio, 1 ounce of carbon becomes grouped with about $2\frac{2}{3}$ ounces of oxygen, and 1 ounce of hydrogen becomes grouped with about 8 ounces of oxygen. Thus it appears that during the ordinary process of combustion in the open air, nearly thrice as much oxygen becomes grouped with an ounce of hydrogen as becomes grouped with an ounce of carbon.

According to the experiments of Despretz, these relative proportionate quantities of atoms of oxygen serve to indicate also the relative proportionate excitation of the phenomenon of heat, developed during the process of the combustion of these two substances.

This result is theoretically to be anticipated from a law of electro-dynamic science, establishing that on every change of groupings of atoms from one static condition to another, dynamic action becomes developed. The greater the number of atoms undergoing this change, the greater must be the consequent development, in some modified form of electro-dynamic action; as in that of heat, light, electrical, mechanical, and chemical actions, &c.

On this principle, it may also be anticipated that food, or vegetable organic formations containing hydrogen in excess, like alcohol, may induce extraordinary excitation in the animal system.

The quantity of air which passes through the lungs of a man of ordinary size, in twenty-four hours, has been found to be about 266 cubic feet, of which $20\frac{2}{3}$ cubic feet are changed into carbonic acid gas.

That a diminution of a supply of oxygen to the lungs is immediately followed by a corresponding diminution of the combustion of carbon and hydrogen therein, and consequently of the development of corporeal strength and locomotive powers of animals, is remarkably manifested during the ascent of lofty mountains. On mountain tops the atmospheric air is less dense than at the level of the sea. In proportion as the air becomes less dense, it contains less oxygen in a given volume inhaled at every breath.

The combustion of the carbon of the fo
of blood in the lungs, diminishes with t

It is noticed on mountains, that t
duces a quicker respiration or panting
compensating supply of the oxygen of
drawn into the lungs.

An intelligent officer of engineers
stated to me, that at an elevation of 800
the sea, whilst ascending the lofty rang
land, on which the city of Mexico is loc
panted in an extraordinary manner; a
remark that the usual amount of food
without suffering from ill health. The
in the lungs being reduced in consequen
ply of oxygen, the quantity of food co
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As the rapidity of the disorganizati
into carbonic acid gas depends on the s
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more rapid combustion; and hence we ha
for the quickened breathing which ensue
of animal force. In the same manner
register or damper-valves for admitting
tact with the carbon on the furnace
necessary to employ more efficient devel
the mechanism of the steam engine.

This fact plainly demonstrates the i
an abundant supply of pure oxygen in
workshops and manufactories. A free
as essential to the vigorous development
as a free supply of food, it becomes as i
to ventilate apartments for facilitating t
furnaces for the combustion of fuel. T
also a consequence of bodily vigor; hence
as well as of self-interest, should induce
this most important subject of ventila
numerous human beings, to whom fresh
being previously inspired, is truly "the

For these reasons the most improve

have been supplied with fresh air by the mechanical power of revolving fan machines. This expedient should be particularly resorted to for ventilating rooms heated by steam-pipes or hot-water-pipes, arranged therein. The economy of fuel available by heating apartments without providing for ventilation, is a pitiful equivalent for the sacrifice of bodily vigor and health. Even club-rooms in London have been ventilated by fans propelled by small steam-engines, adopted for this express purpose. It is a decided advantage attendant on the plan of heating rooms by means of introducing currents of hot air, that a forced ventilation and supply of fresh oxygen is thus continually sustained.

In the combustion of food in the lungs, there is no discoverable development of the phenomenon of heat within the focus of the bosom, as there manifestly is in the combustion of fuel within the glowing furnace inclosed in a locomotive boiler. This discrepancy may appear to invalidate the parallel of the resemblance of the combustion of food and fuel in the mechanisms of animal bodies, and of locomotive engines, for the purpose of developing impulses of motive-power, and the phenomenon of heat.

It is, however, to be remembered that the recoil of the organic formation of the blood to the natural static condition of carbonic acid gas and water, is accomplished gradually, like that which occurs in the process of fermentation (page 570), and whilst circulating through the arteries in the muscles remote from the lungs. In the liquids used in a galvanic battery there is no sudden development of heat, light, and mechanical action. It even requires peculiar arrangements of the plates to render appreciable the electro-dynamic action developed. So in the mechanisms of animal muscles and nerves, it is only by peculiar scientifically devised arrangements of the parts, that the animal motive-power becomes developed.

Having traced the development of animal motive-power to the combustion of food in the lungs, and to the consequent recoiling impulses of Inorganic reaction, as of a bended spring, it is manifest that in tracing animal motive-power to its originating mechanical cause, as in tracing the cause of the movements of the wheelwork of a watch, we must look beyond the recoiling reaction of the spring. We proceed to farther to the originating motive-powe previously applied to wind up the sprin by the recoil of the groupings of atoms water to their natural static conditions, cause which has reduced them to the co of food, as representing the bended s inquiry, it will afford instructive inforn practical illustrations, to demonstrate th the solar action is annually propagated of the organs of different kinds of plants surface in temperate climes, in reducin water to the vegetable organic formatio *fuel.*

In treating of Fluid Inorganic Fo been noticed that water and carbonic aci tant part in the Mechanics of Nature. dergoing vibrations, like elastic spring strained conditions of groupings. They springs of natural terrestrial mechanis or wound up by solar excitation of the other developing the recoiling reaction.

By gathering the wood, or peat, co grains, grasses, fruits or vegetables, cons by the solar excitation of the organs of one acre of ground, the average quant nearly ascertained. By the combustion or peat annually produced on an acre, i boiler, it may be experimentally ascertain *power* may be effectively available there bustion of various vegetable products co the lungs of a man or of a horse, the a *power* available annually, by means of acre of land, may be experimentally asc

It may be computed, as an approxin action of the sun, on an average of the la Northern States of America, is adequat of plants to produce the groupings of ele hydrogen, oxygen, and nitrogen, into the ations of *Food* and *Fuel* in the following average quantities, estimated by weight in a *dry state*:—

1 acre of meadow land produces food,	1½ tons dry hay,	3000 lbs.
1 acre of tillage land " "	25 bush. wheat,	1500 "
1 acre of " " " "	40 bush. Ind. corn,	2100 "
1 acre of " " " "	120 bush. of potatoes, 5400 lbs. when dry,	2000 "
1 acre of forest land produces fuel, of dry wood, about		3000 "

The preceding table comprises a few of the principal kinds of vegetable organic formations, which are consumed in the lungs of animals as FOOD, and in the furnaces of steam engines as FUEL. We shall presently refer to the preceding estimates, as affording a basis for the calculation of the extent of *animal motive-power*, and of *steam-power*, available annually by the electro-dynamic action of the sun on each acre of land.

In calculating the comparative extent of motive-power available from the combustion of wood as fuel in the furnace of a locomotive engine, and of hay as food in the lungs of a horse, it is not to be supposed, for a moment, that the artificial mechanism of a steam engine can be compared with the perfect mechanism of an animal, for developing impulses of mechanical force by the combustion of equal quantities of organic vegetable substances.

EXTENT OF HUMAN MOTIVE-POWER ANNUALLY RENDERED AVAILABLE BY MEANS OF SOLAR EXCITATION ON AN ACRE OF WHEAT-FIELD.

Estimating the quantity of elementary atoms of carbon, hydrogen, oxygen and nitrogen, annually collected by the agency of the organs of wheat plants distributed over an acre of land, and organized into grains of wheat, by the product of a weight of about 1500 pounds, and estimating that about one-third of this weight consists of evaporable moisture, and unavailable husks or coatings, designed for the casing to contain the farina of the grains, and denominated *chaff*, we have about 1000 pounds of *farina*, or fine flour, annually produced from an acre of wheat-fields.

By the preceding table of the component elements of the pure organic substance of wheat flour, constituting the bread consumed by mankind as the principal portion of their food, it appears that this flour consists of about 46 per cent. of carbon, and 6 of nitrogen, thus showing that about 780 pounds weight of atoms of carbon and hydrogen are annually rendered available by means of solar excitation on each acre of wheat-fields, by producing the organic grouping of these elementary atoms into Food for mankind.

It having been found, experimentally, that about 14 ounces of carbon are daily burnt in the lungs of a vigorous man, as tested by collecting and analyzing the quantity of carbonic acid gas daily breathed forth, it may hence be calculated that *animal warmth, and the development of animal motive-power, may be sustained in a vigorous man during a period of more than two and a half years, by means of the annual propagation of the electro-dynamic action of the sun on the organs of wheat plants, covering* ONE ACRE OF LAND.

As the weight of the body of a laboring man varies, commonly, but a few ounces or pounds from year to year, it is manifest that most of the food is consumed in the lungs for propagating electro-dynamic action in the form of animal heat and animal motive-power.

A very considerable portion of the grosser kinds of food consumed by a man is not burnt in his lungs, or reorganized into the textures of his body, as is shown by the following statement of the quantity of food, which is allowed as a "ration," for the sustenance of each able-bodied man in the naval and revenue service of the United States. The following list of articles is copied from advertised proposals for the supply of the articles enumerated, which are deemed amply sufficient for one man for a week:—

Suet,	0 lbs.	8 oz.
Cheese,	0 "	6 "
Beef,	3 "	8 "
Pork,	3 "	0 "
Flour,	1 "	0 "
Bread,	6 "	2 "
Butter,	0 "	2 "
Sugar,	0 "	7 "
Peas,	0 "	7 "
Rice,	1 "	0 "
Molasses,	0 "	9 "

17 lbs. 1 oz. for 7 days = 2 lbs. 7 oz. to supply each man, in public service, one day.

Much of this weight of food being composed of moisture, bones, &c., a deduction is to be made therefrom, to estimate the quantity of organic carbon and hydrogen, which (as stated in Brande's Chemistry) is contained in some of the kinds of meats consumed as food by man.

Beef	contains of nutritious matter in 100 parts, only	26	parts.
Mutton	" " " " " "	29	"
Chicken	" " " " " "	27	"
Codfish	" " " " " "	21	"
Potatoes	" " " " " "	27	"

These reductions bring the amount of organic carbon and hydrogen available, in one day's ration, for combustion in the lungs, nearly to the standard of 14 ounces, as above stated, allowing a small portion for reorganization, to replace the solid parts of the animal mechanism taken up by the absorbent vessels.

The portion of food secreted by the organs, to replace the absorptions of various parts of the body of an adult person, is not, probably, of sufficient magnitude to affect the preceding calculations of the excitation of animal heat, and of animal motive-power of a man, annually rendered available by the propagation of the electro-dynamic action of the sun on an acre of land.

EXTENT OF HORSE-POWER ANNUALLY AVAILABLE BY MEANS OF THE SOLAR EXCITATION OF AN ACRE OF MEADOW LAND.

An acre of common meadow land will produce annually, about one ton and a half, or three thousand pounds of hay.

About 25 pounds of good hay appears to be the average daily supply of food for a horse in New England. This amounts to 7,500 lbs. for 300 working days, or one year. This quantity absorbs the annual growth of grass on about 2½ acres of ordinary meadow land.

By this calculation it appears that the *excitation of the sun on 2½ acres of graminiferous plants is annually required to develope and sustain the animal heat and the motive power of one horse during* 300 *working days.*

The ordinary food supplied for working horses, usually contains a portion of grain, as oats, Indian corn, &c. One peck of Indian corn, or 13 pounds in weight, with an equal weight of hay, constitutes an ample daily allowance of food for a powerful work-horse.

Deducting from the above specified weight of 25 pounds of merchantable hay, an allowance of one-sixth part for imperfect desiccation, there will remain about 21 lbs. of perfectly dry hay, which contains $\frac{54}{100}$th parts in weight of the elementary atoms of carbon and hydrogen, according to the analysis given in the Table of the constituent elements of various kinds of organic substances at page 110. It thus appears that 25 lbs. of common hay, or 21 lbs. of dry hay contain about 11 lbs. of carbon and hydrogen in the quantity of organic matter daily required for reorganization and combustion in the body of a horse.

According to the analytical experiments of Bouissangault,* a horse breathes forth in 24 hours about 5½ lbs. of burnt carbon (2465 *grammes*), and "there are 6504 *grammes* of oxygen inhaled and combined with the carbon to burn it, and convert it into carbonic acid gas."

A man breathes forth about 13½ ounces of burnt carbon daily.

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* Annals de Chimie, et de Physique, lxxi., pages 127 to 136.

In nearly this same relative ratio is found to be the result of the impulses of motive-power available from the vigorous exertion of the power of a man and of a horse.

As a horse consumes about 11 pounds of carbon and hydrogen daily, in the form of food, as above specified, and as only 5½ lbs. avoirdupois appear to be burnt in his lungs daily, it follows that more than half of the food he eats is wasted ineffectively.

This ineffective waste of the food eaten by a horse, may be mainly ascribed to the imperfect mastication of the wiry dry hay. A very considerable mechanical comminution of the ligneous fibres of the stalks of grasses is necessary to open perfectly the cells, containing the soluble materials of organic carbon and hydrogen, whereby they may become absorbed during the process of digestion in the stomach of a horse. For this reason a large portion of the soluble organic carbon passes off in an unaltered state with the insoluble portions of the ligneous fibres of the plants; and the motive-power becomes unavailably wasted in the recoiling steamy exhalations of the fermenting manure heaps, conspicuous in every barn-yard.

Liebig, in his "Animal Chemistry," considers the fæces of animals to represent the imperfectly burned or oxidized portions of the food, and compares it to the soot or lampblack resulting from imperfect combustion in ordinary furnaces.

As if expressly to obviate this wasteful expenditure of organic carbon, the class of ruminating animals are provided with muscles to bring back from the stomach to the mouth the solid ligneous fibres of the grasses, which the animal is thus enabled to subject again to a most perfect grinding or mastication. During a considerable portion of the time occupied by this procrastinated process, the ruminating animals lie down at rest, and consume no more carbon in their lungs than is necessary for sustaining animal heat, and the motive-power requisite for performing the mechanical process of grinding the fibres of the plants.

The most powerful muscles in the body of a hen are employed to grind the food between the pebbles, which serve as the upper and the nether millstone.

The palpable economy of food rendered available by a greater development of animal motive-power in the bodies of ruminating animals, such as the ox, as compared with the horse, by this elaborate process of the comminution of their food, should long ere this have attracted more attention from agriculturists, who rear animals for service and for the shambles. Philosophy teaches us that a very perfect mechanical separation of the wiry and flinty organic compounds, which constitute the protecting covering and the skeleton framework of plants, is necessary, in order that the soluble portions of carbonaceous matter may be dissolved therefrom in the process of digestion in the stomach, and absorbed into the circulating blood.

There is the same reason for recourse to mechanical processes for grinding hay for a horse, as for grinding wheat and corn for man. The grinding molar teeth of a horse are amply adequate to masticating green succulent herbage; but the labor of the perfect mastication of 25 lbs. of hard dry hay every day, in addition to the full performance of their allotted tasks of labor, requires no small portion of their physical powers. After being fatigued by daily toil, work-horses are usually compelled to appropriate several hours to the chewing of a score of pounds of ligneous fibres of hay before they can lie down to rest. Consequently the period of actual labor for a horse is practically limited to only about 8 hours per day, to allow the animal time to perform the duty of a miller in grinding his daily grist. For the same reason 8 hours per day would be the period of the daily labor of a man, were he compelled to pass several hours in chewing the hard dry grains of wheat, which, for this very good philosophical reason, are always transferred to the miller and baker, to reduce them to the labor-saving consistency of bread. In Holland I have noticed that the horses are frequently fed with grain reduced to the form of loaves of bread. These facts demonstrate the importance of the preliminary process of the preparation of food by machinery, actuated by water-power or steam-power, both as a saving of time, and of more costly animal motive-power.

The practice of mankind, from the earliest dates recorded in history, serves also to demonstrate, that by exciting a partial tendency to decomposition of the organic carbon of food, as in the incipient fermentation induced by yeast in leavened bread, chemistry was applied to the useful arts by every frugal housewife, before it had a name as a science. And, doubtlessly, the same reasons exist, even to a greater comparative extent, in the preparation of the grosser materials of food for work-horses.

The process of chopping hay and straw at present in use, may be deemed the philosophical commencement of a system of a more minute comminution of hard wiry vegetable substances, for the purpose of obtaining the greatest possible development of animal motive-power from their combustion in the bodies of working animals.

These considerations also serve to exhibit the lack of intelligence manifested by farmers and carriers, who, from mistaken notions of economy, withhold a generous supply of food from their working animals; and, notwithstanding, require of them a full exertion of their physical strength in the performance of their allotted labors. The manager of a steam engine, who would thus stint the supply of carbon to his machine, and would still expect a full performance of its labors, might well be deemed an unfit person to be intrusted with his charge. In addition to the actual loss of labor of the animal, or of the steam engine, the unproductive loss of time of the attendant is also involved.

WASTEFUL COMBUSTION OF FOOD IN ANIMAL BODIES, BY WANT OF PROPER PROTECTION FROM COLD WEATHER.

In connection with the subject of economizing the available use of the motive-powers of working animals, producible by the combustion of carbon in their lungs, it should be remembered also by agriculturists, that no small portion of the organic carbon in hay and grain may be burnt merely to sustain animal heat, without contributing either to nutrition or motive-power. Philosophy, therefore, teaches us that there is an actual economy in providing comfortably warm shelters for animals, during the inclement season of winter. A warm barn, like a warm house, renders unnecessary the combustion of a considerable quantity of costly organic carbon in the lungs, to sustain the due temperature of the *blood-heat* of cattle clothed with short hair.

Before any of the food of cattle can be burnt efficiently for developing mechanical forces available for purposes of labor, or become reorganized in the form of available secretions of the milk, flesh, or fat, constituting human food, there must be necessarily burnt, unproductively, sufficient of the carbon contained therein to maintain the temperature of their bodies at a certain determinate standard point. This determinate point is found in the body of man to be 98° of Fahrenheit's scale, and is marked thereon "blood-heat."

In like manner a sufficient quantity of fuel must be unproductively burnt in the boiler of a locomotive engine to raise the temperature of the water to 212°, as similarly marked on the scale, "boiling point."

To economize the wasteful consumption of fuel in locomotive engines, which would occur from the rapid diminution of excitation if exposed naked to the cold blasts of wintry weather, the bodies of the boilers are carefully covered with non-conducting casings of wood. In like manner to economize the wasteful consumption of food in animals, which would occur from the rapid diminution of excitation if left exposed naked in the polar regions, they are naturally covered with the most perfect non-conducting coats of fur and down. And still further to economize the combustion of the limited provision of carbon and hydrogen treasured up in their bodies in the form of fat, to be burnt as fuel in their lungs, they are so constituted as to pass the long cold winters in a motionless torpid state, thus manifestly avoiding all waste of fuel necessary to sustain motion, for the purpose of reserving the whole effective power of it for sustaining the electro-dynamic excitation necessary to prevent the freezing of their bodies.

And, finally, as if to carry out to perfection the practical application of electro-dynamic science, the dark colors of the external coverings of animal bodies in the polar regions become changed to a *white color*, which, it is well known, diminishes the radiation of heat.

Motives of self-interest, as well as of humanity, thus dictate to farmers and others, who have charge of brute animals, designed either for labor or for the shambles, to provide for them comfortable shelters from inclement wintry storms, in order to save the unavailable waste of the portion of their food, which otherwise becomes necessarily burnt in their lungs to sustain the due temperature of their bodies. By careful attention to this subject, it is practicable to reorganize into the useful formations of fat and muscles of animals designed for the shambles, or availably to employ as a source of motive power, the greater part of the quickening harvests of vegetable organic formations of food, which are annually produced by the excitation of the sun on each acre of land.

EXTENT OF STEAM-POWER ANNUALLY AVAILABLE BY SOLAR EXCITATION OF AN ACRE OF FOREST LAND.

There is a great difference in the rapidity of the growth of various kinds of forest trees. The oak and hickory produce annually less bulk of wood for fuel than the ash, chesnut, pine, birch, &c. The first named two kinds of wood, however, are found to be specifically heavier when dry, than the latter; consequently there are more atoms of carbon and hydrogen condensed into the same bulk of the woody fibres of hickory and oak. As the extent of motive-power is found to be in proportion to the quantity of atoms of organic carbon and hydrogen contained in woods of different species, the relative values of different kinds of these organic substances, for combustion in furnaces, admit of being estimated more exactly by weight than by measure, when rendered equally dry, or devoid of moisture.

In the preceding tabular estimate of the weight of 3000 lbs. of wood as the annual product of an acre of forest land, the dry wood is estimated to be composed of a grouping of elementary atoms of carbon, hydrogen and oxygen, condensed to the specific gravity of about ·6, as compared with the specific gravity of water. But as all wood ordinarily used for fuel contains considerable moisture, the annual product of the perfectly dried wood of these forest trees growing upon an acre of thrifty woodland, is still less than 3000 pounds.

When estimated by measure in cord-wood, this weight will constitute about 100 to 128 cubic feet.

It is commonly found to require the combustion of about nine to twelve cubic feet of ordinary cord-wood per day, to develope steam-power equivalent to that of one horse. Assuming an average of ten cubic feet per day, and the annual product of an acre of land to be 128 feet, we have the extent of motive-power rendered annually available by the solar excitation of an acre of forest land, in organizing atoms of carbon and hydrogen into fuel for operating a steam-engine.

By this estimate it appears that the annual growth of wood on an acre of woodland is adequate to rendering available a recoiling inorganic reaction, adequate to operating a steam-engine of one horse-power about thirteen days, the annual growth of about twenty-three acres being at this rate adequate for three hundred working days, or one year.

By reference to the Table of the constituent elements of various kinds of organic substances (page 110), it appears that "Woody Fibre" contains 50 per cent. of carbon, and about 5 per cent. of hydrogen, or 55 per cent. of these organic atoms. About one-fifth part in weight of cord-wood being composed of moisture, sap, &c., 3000 lbs. of this kind of fuel may be estimated to contain about 1300 lbs. of these two kinds of elementary atoms, which are annually reduced from the aëriform state of carbonic acid gas, and from the fluid state of water, to a fixed solid state of grouping, produced by the agency of the organs of forest trees, spread over an acre of land.

The vast quantities of atoms of carbon, which have been passed through the organs of plants of all kinds, during the countless ages which geologists assign to the probable existence of this earth, at the rate of 1300 lbs. per acre, must thus have absorbed, several times over, all the carbonic acid gas now floating in the atmosphere. Were it not for the unceasing recoil of these groupings of atoms from their constrained static conditions of organic formations, by the processes of combustion and fermentation, and the consequent resolution of their compound elements again into carbonic acid gas, the whole of this gas, existing on the surface of this earth, might finally become reduced to organic solid conditions of groupings in the various kinds of plants and animals, and the further extension of the races of the vegetable and animal kingdoms would be brought to a stand.

On the contrary, with the extension of the combustion of forests, cleared off from the surface of the earth, and of the vast beds of mineral carbon extracted from beneath its surface, for combustion, it is to be supposed that carbonic acid gas must become reproduced faster than it is reduced to a fixed solid state by vegetable agency; and the luxuriance of vegetation may hence become gradually increased, as a compensating reaction, to supply more abundantly the increasing wants of the augmented population of the earth, unless absorbed by coralline formations.

The science of geology teaches us that, before the creation of man on this planet, plants were created. Their expanding leaves courted the excitation of the sun, and commenced the process of collecting and grouping together atoms of carbon and hydrogen into the constrained static condition of organic matter, now constituting mineral coal, apparently with the design of providing a store of this natural motive-power, in anticipation of the advent of man.

This kind of fuel, by some unexplained convulsion of the earth, has been buried, securely from wasteful combustion, beneath the cold wet strata of the present coal-fields of our planet. By this providential arrangement, it appears that the organs of living plants, quickened by the superabundance of carbonic acid gas and the prevalence of water, in the dawn of the existence of this earth, were employed effectively as machines for rendering the action of the primeval sunshine on this planet available to the human beings destined, in after times, to occupy it. We may imagine, whilst we enjoy the brilliant light of coal gas, by which our cities are illuminated, that we participate in the benefit of antedeluvian sunbeams. And since the creation of man thereon, the surfaces of the same regions, which constitute coal-fields, are still found to be surpassingly fertile in producing plants, serving to reduce carbonic acid gas to the organic groupings constituting Food, as well as Fuel, necessary for the development of energetic impulses of motive-power.

Thus, the science of geology serves to teach us what the solar excitation of the organs of plants has done, in former times, in collecting and organizing elementary atoms of carbon and hydrogen into fuel, in the form of mineral coal; whilst the science of agriculture serves to teach us what the same cause can do, at the present time, in collecting and organizing, on various portions of the earth's surface, the same kinds of elementary atoms into food as well as fuel, in the form of grasses, seeds, or fruits, and woody fibre. We are taught to trace the origin of mineral coal as directly to the source of antediluvian excitation of the sun, acting on the leaves of antediluvian plants, as we have traced the origin of modern wood-piles, in farmers' yards, to the more recent excitation of the organs of plants by the present daily sunshine.

Both the sciences of geology and chemistry teach us that, from the earliest formation of this earth, solar excitation has been producing groupings of atoms of carbon, hydrogen and oxygen, which practically subserve the purpose of becoming a sort of reservoir for accumulating, through the organs of plants, constrained static conditions of counterbalanced Organic and Inorganic forces, which, in after ages, are resolvable by man into dynamic impulses constituting SOURCES OF MOTIVE-POWER.

An estimate of the comparative areas of the coal-fields of some of the principal nations of the earth has been represented by the figures at page 123.

The contemplative mind recognizes as much fatherly care in providing for the anticipated wants of man in the abundant stores of organic vegetable formations of mineral coal, securely treasured up beneath ancient carboniferous fields, as in providing for the present supply of his immediate wants in the bountiful golden harvests, which are annually quickened, and wave on its sunny surface, as if instinctively rejoicing in their vegetable life.

By pursuing these interesting analogies, it admits of demonstration that the originating source of the natural motive-power, available on the surface of our planet, is ascribable to the electro-dynamic action of the sun; so that whether we regard the sublime development of mechanical force displayed in the rapid movement of a huge war steamer, steadfastly advancing on its way through adverse billows that are left behind it, covered with flashing foam;—the sublime mechanical force displayed by the movement of a locomotive engine over a railroad, followed by its long train of appended cars, whizzing off at the fearful rate of thirty or forty miles an hour;—the graceful movements of a belle, "tripping on light fantastic toe" in the mazes of a dance;

or, finally, the movements of the ever faithful magnetic needle, balanced on its pivot, in the mariner's compass-box; we may unhesitatingly ascribe them all to the same originating cause of "sunbeams."

It is to be remembered, however, that *vitality*, the skilfully constructed locomotive mechanisms of animal bodies, and the "light fantastic toe," are not ascribable to sunbeams; but simply the origin of the impulses of mechanical force which are excitable and controllable by vital agency.

Vitality, as being an immaterial essence, is entirely beyond the province of mechanical philosophy, and is recognized only by the modified states of motion and rest of passive matter, producible at the pleasure of volition.

COMPARATIVE EXTENT OF MECHANICAL FORCE AVAILABLE BY THE COMBUSTION OF ORGANIC FORMATIONS IN THE LUNGS OF A HORSE, AND IN THE FURNACE OF A STEAM-ENGINE.

In order to institute a comparison of the extent of motive-power exerted by a work-horse, and by a steam-engine, it becomes necessary, preliminarily, to establish a common standard of the admeasurement of the effective impulses of the mechanical force severally exerted by them.

The average motive force exerted by a work-horse of ordinary strength, by the test of numerous experimental trials, has been found to be adequate to lifting a weight of 100 pounds, suspended by a rope passing over a pulley, whilst the animal travels forward with a regular speed of little more than 2½ miles per hour, or more precisely, 220 feet per minute. This extent of physical force a horse is capable of exerting about eight hours per day. Exhaustion, and the necessity for fresh supplies of organic carbon as food, then require an intermission of muscular action.

To reduce this sum of the effective motive-power of a horse to a single expression, as a standard effect, it is necessary to multiply the weight (100 lbs.), by the number of feet of height to which it is raised: 100 × 220 = 22,000. This aggregate result of 22,000 may represent an effect produced by lifting 1 lb. 22,000 feet high, or, 22,000 lbs. 1 foot. This result has been generally assumed as representing the average power of work-horses.

In adopting a comparative standard of a *horse-power* to measure the force exerted by steam-engines, one of the original inventors of these machines added about one half to this result, to prevent any disappointment to those who purchased steam-engines as a substitute for the horses previously employed. Boulton and Watt, in their calculations of the *horse-power* of their improved steam-engines, assumed the conventional standard of 33,000 lbs. raised 1 foot high, instead of the actual standard of 22,000 lbs. raised 1 foot high; and they, moreover, calculated their steam-engine to operate during the 12 hours per day, in accordance with the limitation of the hours of human labor, instead of 8 hours, as above stated, constituting the limits of the labor of a horse. Hence the following formula represents the comparative standards of the actual power of a horse and of the conventional *horse-power* of steam-engines.

Relative dynamic power of a common horse and of a steam-engine of "one horse-power."

22,000 × 60 minutes × 8 hours = 10,560,000 lbs. raised 1 foot high = ACTUAL POWER OF A HORSE. 33,000 × 60 minutes × 12 hours = 23,760,000 raised 1 foot high = HORSE-POWER OF A STEAM-ENGINE. Thus the actual power of an ordinary work-horse is to the rated horse-power of a steam-engine in the ratio of 10 to 23; or a horse must work 2$\frac{7}{8}$ days, of 8 hours, to accomplish a development of impulses of mechanical force equal to that effected by the rated "one horse-power" of a steam-engine in 12 hours of one day.

In 2$\frac{7}{8}$ days there are consumed in the lungs of a horse (at the rate of 11 lbs. per day, as before stated), about 31 pounds of carbon and hydrogen.

In 1 day of 12 hours there are consumed in the furnace of a steam-engine 8 lbs. of organic carbon, or fuel, per hour, = to 96 pounds; being over threefold more of organic formations of carbon burnt in the furnace of a steam-engine, than in the lungs of a horse, to develope an equal extent of motive-power.

In the preceding calculations the electro-dynamic action of the sun, propagated to the surface of 2½ acres of meadow land, is shown to be requisite to reduce a quantity of atoms of carbonic acid gas and water from their natural static condition to the constrained static condition of FOOD sufficient for a work-horse for one year of 300 working days of 8 hours each. But the standard of the actual *animal* "horse-power" being less than that of the *steam* "horse-power" in the ratio of 10 to 23, as before explained, it will be necessary to consider 5¾ acres of meadow land as equivalent to sustaining a motive animal power equal to that of a one-horse steam-engine power for one year. And the annual growth of wood for fuel on 23 acres of land being requisite for sustaining the motive "one horse-power" of a steam-engine during the same period, it follows that the electro-dynamic action of the sun, propagated in the modified form of the combustion of FUEL for operating the artificial mechanism of a steam-engine, developes only ¼th of the extent of available impulses of mechanical force, which are developed by the combustion of FOOD in operating the more perfect mechanism of a horse.

These calculations apparently demonstrate that the natural mechanism of a work-horse is about fourfold more effective for rendering available the propagation of the electro-dynamic action of the sun on a given area of terrestrial surface, than the artificial mechanism of a steam-engine; and they serve to furnish a striking evidence of the superior perfections of the works of nature to those of art.

But there is a difference in favor of the steam-engine in point of *economy of the cost of procuring the organic carbon* for exciting and sustaining these several available impulses of mechanical forces. The carbon for the steam-engine is abundantly obtainable from the vast beds stored up in the mineral veins in the earth; where it has been elaborated and prepared by the solar action on the broad acres of the earth, before man was created to inhabit it. But no such provision of carbon in a state suitable to be used for food, is found naturally provided for supplying the necessary combustion in the lungs of animals; for by the wise decrees of Providence, man is destined "by the sweat of his face to eat bread."

The relative market value of the organic substance of carbon in the form of *food* for a horse, and of mineral *fuel* for the steam-engine, is estimated by the pecuniary standard of the cost of procuring it. In favorable locations mineral coal or carbon may be procured for less than 10 cents for the 96 pounds required to operate a steam-engine for 12 hours; whereas the carbon in the form of the hay and farinaceous products necessary to actuate the mechanism of a horse for 2⅞ days, to render available an equal amount of impulses of mechanical force, may cost many fold more.

The following is an approximate estimate of the actual cost of the food, or organic substances, necessary for rendering available the power of a horse for 2⅞ days, as compared with the cost of coal for fuel necessary to produce an equivalent power by a steam-engine for one day.

13 pounds of hay per day for 2⅞th days = 37 lbs. at ¾ ct. per lb.	28 cents.
1 peck Indian corn per day for 2⅞th days = 2⅞th pecks, at 50 cts. per bushel	35 "
Cost of organic carbon serving as food for a horse 2⅞th days, equivalent to one horse-power of a steam-engine	63 "
96 pounds mineral coal, at $5 per ton, of 2000 lbs. for each horse-power of engine, 1 day	24 "
Comparative economy of expense of fuel in favor of steam-power, per day	39 cents

These estimates will of course be found to vary where the costs of the organic formations used as food for a horse and as fuel for a steam-engine, vary from the above specified prices.

By the above comparative estimate, it appears that the cost of fuel for a steam-engine is less than half that of food for a work-horse, to develope an equal extent of impulses of mechanical force, on the seaboard of the United States.

In tracing to its originating source the cause of the motive-power which moves the mechanism of a watch, we do not consider that we have arrived at the final originating cause of the impulses when we perceive the reaction of the recoiling spring. We do not for a moment imagine that the spring is possessed of any "inherent" or "innate" power of winding itself up, and of then recoiling. We reflect that the natural static condition, or state of rest, of the spring, is that of a straight ribbon of metal, not of a bended coil. The recoil, we thus feel assured, is a mere reaction on the withdrawal of force previously applied to *wind it up*.

Our attention becomes thus immediately directed to some precedent cause of dynamic action which must have been applied to produce the temporary static condition of the deflection, or the spiral coiling of the wound-up spring, as the real source of the impulses which we behold on its recoiling when set at liberty.

So in tracing out the true source of the motive-power developed by the recoil of groupings of atoms of carbon, hydrogen, oxygen and nitrogen in all vegetable organic formations of FOOD and FUEL, from their temporary constrained conditions of groupings to the permanent natural static condition of carbonic acid gas and water, we cannot hesitate to ascribe it to some precedent cause, which has originally produced the change of atomic groupings from inorganic to organic vegetable formations. This original cause has been shown to be the electro-dynamic action of the sun on the organs of plants, and to be continuously propagated in connection therewith in the specific form of ORGANIC ACTION.

It is therefore manifest that the originating source of motive-power developed during the combustion of organic formations of carbon, either as fuel in the mechanisms of locomotive engines, or as food in the mechanisms of animal bodies, is not ascribable to an original force developed by the chemical decomposition or combustion of such vegetable bodies, but to a precedent, primary, exciting cause of solar excitation on the mechanisms of plants, as a cause of natural motive-power, which reduces these atoms of carbon, hydrogen, nitrogen and oxygen to their static conditions of organic formations.

We pass by the phenomena of the chemical decomposition of fuel and food, to arrive at the precedent cause of their composition into extraordinary groupings of wood, mineral, coal, wheat, corn, &c.

So also in tracing out the cause of WATER-POWER to the originating source of the impulses thereby rendered available, we are taught rather to regard the primary cause of the disturbance of the natural static condition of the water, resting at the level of the surface of oceans, than the reacting force of gravitating impulses. These represent the recoiling impulses of a wound-up watch-spring, being temporarily overpowered by the electro-dynamic action of the sun.

The preceding facts and calculations amply demonstrate not only the propagation of the electro-dynamic action of the sun in producing groupings of atoms of carbonic acid gas and water into the constrained static conditions of *Food* and *Fuel* through the mechanisms of the organs of plants, constituting ORGANIC ACTION, but even the extent of this solar action on each fertile acre of the earth's surface exposed thereto. And the comparative extent of the resultant propagation of solar electro-dynamic reaction has also been illustrated, by the practical development of *Steam Power* and of *Animal Power*, during the recoil of the organic formations of fuel and food to their natural static conditions of carbonic acid gas and water.

It has been shown also (page 38) that this resultant reaction, developed during the combustion of fuel in the mechanism of a locomotive boiler, is not only capable of propagating impulses through the medium of electricity, in the modified form of mechanical action, but also in the palpable form of electric sparks, of Light, of Heat, and of Electro-magnetic action. And it has also been illustrated in the chapter on Standard Tests of Physical Science (page 180), that the motor nerves and muscles of sentient beings constitute real electroscopes, most exquisitely sensitive to the least disturbance of the state of rest of electric matter, as developed by the phenomena of muscular contractions. We shall now demonstrate that living animals are endued with the power of controlling the propagation of mechanical action developed by the combustion of food within the mechanisms of their own bodies, in the several specific forms of the excitation, not only of muscular contractions and consequent animal motive-power, but also of palpable Electric sparks, of Light, Heat, &c. We shall then show that the same mechanical laws govern the excitation and development of the powers of animal mechanisms, which govern the excitation and development of the powers of the artificial mechanisms of a locomotive engine.

ANIMAL INTELLIGENCE, CONSIDERED AS CAPABLE OF DIRECTING THE ELECTRIC ACTION DEVELOPED BY COMBUSTION, IN THE LUNGS, OF THE FOOD PRODUCED BY SOLAR EXCITATION OF THE ORGANS OF PLANTS.

> "That in his inner heart he traceth,
> What he produces with his hand."—*Schiller.*

The same electroscopic contractions and movements of animal muscles, which are resorted to as tests of electric excitation, are also deemed tests of the presence of VITALITY in the mechanisms of animal bodies. The power of controlling the excitation and propagation of mechanical action through the medium of electric matter, appears, therefore, to be the sole test of the presence of Vitality.

In treating of the standard tests of Physical Science (page 176), reference has been made to the beautiful and poetical, as well as philosophical idea advanced by Galen, suggesting that the immaterial essence of the minds of intelligent beings is enthroned in an atmosphere of "pure ether or luciform vehicle," as if too refined for immediate contact with the grosser matter in which it becomes embodied during its brief existence on earth.

It has been premised (page 179), that all parts of the bodies of animals, except the organ of the brain, and the nerves connected therewith, have been found to be contrived for performing certain specific mechanical functions. The brain and nerves have been found, experimentally, to subserve the purpose of developing and controlling the propagation of electro-dynamic action, the latter representing telegraphic wires extended between the muscles and external parts of animal bodies. It remains now to demonstrate the truthfulness of the preceding analogies.

A certain class of fishes, low in the order of created beings, and living in muddy pools of water, have been found to be actually endowed with a power of wielding, at their pleasure, electric discharges, representing the mythological thunderbolts of Jupiter, sufficient to kill the small fishes serving as their prey, and to stun their most potent assailants. The endowment of this class of fishes with powers of propagating electric discharges in palpable flashes and sparks, appears to have been purposely designed for half unveiling the mode of propagating Organic action; in the same manner as the lodestone has similarly served to disclose the mode of propagation of Inorganic action.

Power of Exciting and Controlling Electricity, possessed by certain Fishes.

The extraordinary power of producing benumbing sensations and shocks, possessed by electrical fishes, was noticed in the earliest records of science; as appears by the writings of Aristotle, Pliny, and other ancient authors. These fishes were anciently known by various names, referring to the benumbing sensations which they excited in persons touching them.

After the discovery of the shocks producible by means of an electrical jar, the similarity of the sensations proved to be so remarkably striking, as to obtain for them the name of "electrical."

Numerous accounts of electrical fishes have been published in various periodical works, and even in distinct treatises, illustrative of their physiological structure, and of their energetic powers of physical action.*

There are only three kinds of electrical fishes found in the southern part of Europe; viz., the Torpedo, Occelata, and Marmorata, and about twice this number in tropical climates: viz., the Gymnotus, Silurus Electricus, Tetraodon, Rhinobatus, Trichiurus Electricus, and Torpedo Occidentalis. Of these the torpedo, gymnotus, and silurus, are the most remarkable for their extraordinary powers. They have been consequently more particularly selected for experimental investigations.

The TORPEDO is a fish of the species of the ray, and is common in some parts of the Mediterranean sea. Its body is about one foot in length, and much of the space between the gills and pectoral fins is occupied by a great number of small membranous tubes or cells, arranged like those of a honeycomb, with horizontal partitions, as exhibited in the dissected portion of the back, in the annexed wood-cut. These cells are all filled with a mucous substance, and are furnished with tissues of nerves. No use can be imagined for this peculiar arrangement of cells, unless it be to subserve the purpose of a galvanic battery.

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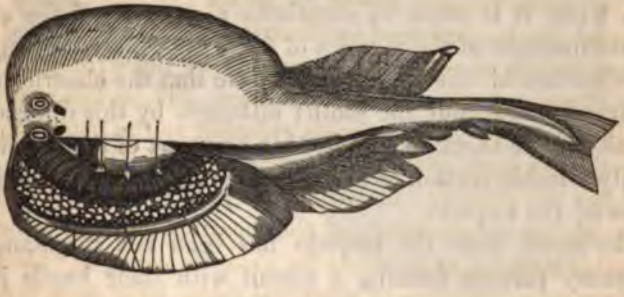
* The reader is referred to accounts of the power of electrical fishes, published in the Philosophical Transactions, 1773, 1774, 1832, 1834, 1839, and to the annals of various scientific institutions of the continent of Europe. Among these writers are, Hunter, John Davy, Gay Lussac, Colladen, Matteucci, Walsh, Ingenhouse, Humboldt, Bonpland, Faraday, Rudolph Müller, &c. In the 4th vol. of Becqurel's Treatise, and in the second of Tiedman, the reader will find interesting information on this subject.

Fig. 174.



Each of these vesicular organs is arranged in such a manner in the body of the fish, as to present its base to the surface of the belly, and its top to that of the back. Mr. Hunter states that he counted 1182 of these cells in a single organ, all connected by nerves, which are conductors of electricity, like connecting wires; for when the nerves are cut off, all signs of electricity vanish entirely, although these signs become manifested even after the heart of the animal has been cut out, and his skin stripped off.

The circuit of the electric charge is directed between the back and the belly of the fish.

By experiments made by Galvani, it appears that the prepared legs of frogs become convulsed on being placed on any part whatever of the surface of the torpedo, or on being extended upon the wet surface of a table at a certain distance from the torpedo, even whilst the fish appears to be in a tranquil state. Hence, Volta inferred that the organs developing electrical excitation must be in constant action, from this continuous transmission of the fluid from the upper to the lower surface of his body whilst in a tranquil state. It is not, however, very probable that any kind of fish *out of water* can remain in a very "tranquil state," as supposed by Volta, and the continual excitation in this case may be ascribable to the continuous agitation of the fish, on being withdrawn from his accustomed element.

A shock is felt in the joints of the fingers, extending to the elbows, and shoulders, when the finger is placed on any part of the torpedo except the tail, which may be touched with impunity. The lateral discharges made by the torpedo through the adjacent water have been compared to the discharge of a Leyden jar over wet cloth, when it is made to constitute a portion of the circuit. The contractions of the muscles of frogs' legs, placed on any part of the surface of this cloth, demonstrate that the electric current is diffused throughout the cloth; although by this diffusion the intensity of the shock experienced in any part of the circuit may be only a feeble portion of that which circulates from the electric organs of the torpedo.

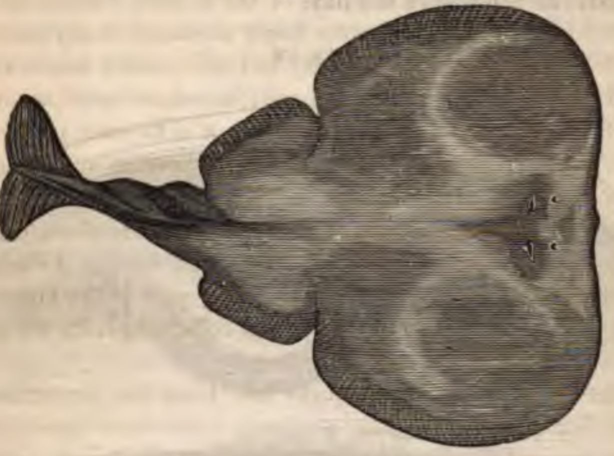
The shock from the torpedo has been felt simultaneously by twenty persons forming a circuit with their hands joined, at the instant when the first person of the circuit touched with his finger the belly of the fish, and the last one touched the back.

Mr. Walsh has published an interesting account of experiments with this fish. He observes that "the shocks given are manifestly *subjected to the will* of the torpedo, for he may be often touched several times without giving a shock; but on irritating him, by pinching the fins, one may be pretty sure to receive shocks of redoubled violence." Mr. Walsh counted twenty shocks given by a torpedo in one minute.

The electric sparks excited by the torpedo, have been rendered distinctly visible by Matteucci, who applied two metallic armatures, the one to the back, and the other to the belly, two slips of gold leaf being arranged very near each other in the connecting circuit. On irritating the torpedo, a brilliant spark may be seen between the pieces of gold leaf.

A new species of Torpedo has been discovered on the western shores of the Atlantic, denominated the TORPEDO OCCIDENTALIS, by Mr. Storer, who has given an account of one of them, taken at Wellfleet, Massachusetts. This species, represented in the annexed figure, has been described as varying in weight from 20 to 200 lbs. The shocks given by it, according to the testimony of fishermen, "are sufficient to prostrate a man," and are perceptibly felt by any one holding the rope attached to a harpoon, plunged into the body of the fish. "The *electrical* lobes of the brain are larger than the whole remainder of that organ; and the volume of the *electrical* nerves greater than those supplying all other portions of the animal."

Fig. 175.

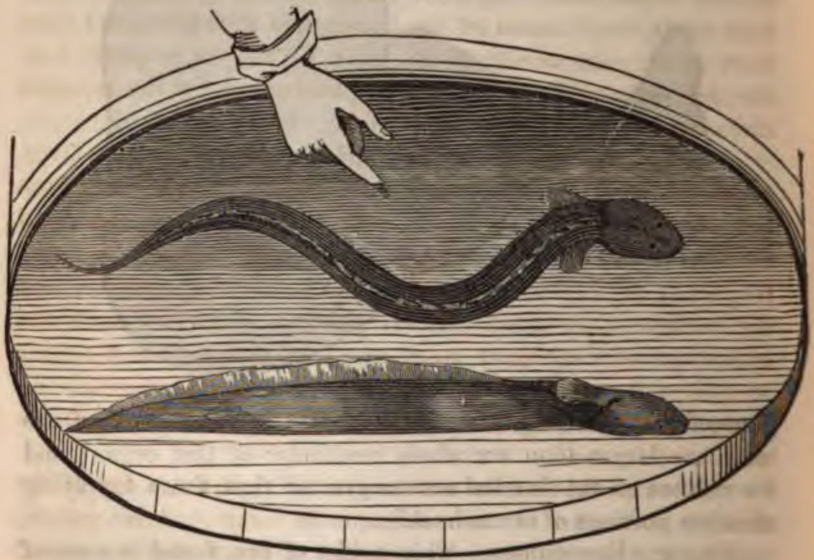


SILURUS ELECTRICUS.—This species of fish, found in some of the rivers of Africa, is provided with feelers, which are projected above the surface of the muddy bottoms, wherein his body lies concealed. The Silurus waves these feelers to and fro, so as to counterfeit the appearance of moving worms. The smaller fish, decoyed by this alluring prospect of food, approach, and become struck motionless by the powerful electric shocks transmitted through them; and in this state they are easily seized as prey.

THE GYMNOTUS is a species of eel, found in some of the rivers of South America. Its length is about five or six feet, the body being of nearly uniform thickness throughout, as represented in the figure. The electrical organs are distributed on each side of the body throughout nearly the whole length of it.

Humboldt, during his travels in South America, had an opportunity of witnessing the extraordinary powers of the Gymnotus, as well as of experiencing them personally, from having incautiously trodden on one of them, soon after being drawn out of the water. From the violence of the shock he received, "he continued to feel pain in his knees, and in almost every joint of his body, all the rest of the day."

Fig. 176.



A very interesting account of the truly formidable power of this species of eel in its native waters in South America, is contained in Humboldt's narrative, as published in the Annales de Chimie, tome xi. page 255, from which I have made the following extracts.

"The Indians told us they were going to catch these eels with horses. We could form no idea of this extraordinary mode of fishing; but soon we saw our guides returning from the plains, where they had surrounded and captured some wild horses and mules. They brought with them about thirty, and drove them forcibly into the pool.

"The extraordinary splashing caused by the feet of the horses brought the eels out of the muddy bottom, and excited them to the combat. They appeared of a yellowish livid color, swimming on the surface of the water like huge water snakes, and making their way beneath the bellies of the horses and mules. The struggle which ensued between these animals, endued with such widely different organizations, presented a most picturesque spectacle. The Indians, provided with harpoons, and long slender cane-poles, closed around the pool, some of them climbing the branches of the trees, which extended horizontally over the surface of the water. By their wild cries, and by means of their long reeds, they headed off the horses, and thus prevented them from gaining the border of the basin. The eels, rendered furious by the commotion, defended themselves by the repeated discharges of their electrical batteries.

"For a long time the victory appeared to be in their favor. Several of the horses had sunk down under the violence of the invisible discharges, which they were receiving on all sides, and on their most sensitive vital organs. Stunned by the force and frequency of the shocks, they now and then disappeared beneath the surface of the water. Others, panting, with mane erect, and eyes expressive of agony, were regaining their feet, and seeking to escape from the attacks, by which they were overwhelmed. They were constantly driven back again by the Indians to the middle of the pool.

"Notwithstanding the exercise of all vigilance, a few of the animals succeeded in their attempts to escape. After gaining the bank, they appeared to stumble at every step, to extend themselves upon the sands as if their limbs were benumbed and overcome by fatigue, from the electric shocks of the gymnoti.

"In less than five minutes, two of the horses were drowned. They were not probably killed outright by the shocks, but simply stunned; and in this state they were drowned, being unable to recover themselves during the prolonged struggle between the other horses and the electrical eels.

"We had begun to entertain doubts whether this mode of fishing might not terminate by the successive destruction of all the horses employed in it; but gradually the impetuosity of this unequal conflict became diminished, the exhausted eels dispersing; for they require a long repose and ABUNDANCE OF FOOD TO REPAIR THE LOSS OF THE GALVANIC FORCE EXPENDED.

"The mules and the horses finally appeared less frightened, their manes drooping, and their eyes expressing less terror. The gymnoti began timidly to approach the border of the bogs, where they were taken by means of the little harpoons attached to long lines.

"Whilst the lines were kept dry, in raising the fishes into the air, the Indians were not affected by any sensible shock. In a few minutes, we had five large eels, the greater part of which were very slightly wounded. Several others were taken, towards evening, by the same means.

"Some of the gymnoti, which I measured, were five feet, to five feet three inches, in length (nearly six English feet), and about three and a half inches in diameter.

"Two rows of little yellow spots are symmetrically arranged along the back, from the head to the end of the tail. Every spot surrounds an excreting duct. The skin of the animal is coated with a slimy matter, which (as tested by Volta) serves to conduct electricity twenty or thirty fold better than water."

One of this species of eels—a large gymnotus—was exhibited for several years in London, where ample opportunities were afforded to make experiments upon his electrical powers.

The most effectual mode of exhibiting the electricity, excited by his animal organization, was found to be by the contact of two copper plates, fitted like saddles, to be applied near his head and his tail. A stiff iron rod was soldered to each of these, and the whole was coated with caoutchouc, to insulate them, excepting only the parts applied in contact with the fish.

The shocks were found to be most powerful when the two conducting wires were placed, the one near the head, and the other near the tail. The circuit was completed by holding the wires one in each hand. On whatever part of the animal these conductors were placed, the current of electricity was always found to proceed from that which was nearest to the head, to that which was nearest to the tail.

It is stated by Mr. Sidney that, on giving the animal a good shaking with these wires, he became angry, emitting a discharge, which caused an electric spark to pass between a knob and piece of gold leaf, which was *partially burned thereby*. Compound substances *were decomposed*, steel needles were *magnetized*, and other phenomena were presented, similar to those produced by a regular galvanic apparatus. After the eel had been apparently exhausted, a small fish, which had been provided for his food, on swimming under his body, received a shock that killed it instantly, "as if it had been struck by lightning," as Professor Faraday adds; after which the eel swallowed its prey.

Mr. Sidney also states that "Captain Basil Hall was fairly laid prostrate on the floor by a shock; and the same happened to a bold life-guardsman, who came down upon the boards with the clang of cuirass and sword, to the great amusement of the spectators."

Mr. Faraday, in summing up the powers of electrical fishes, observes: "I cannot refrain from pointing out the enormous absolute quantity of electricity, which the animal must put in circulation at each effort. It is doubtful whether any common electrical machine has as yet been able to supply electricity sufficient in a reasonable time to cause true electro-chemical decomposition of water; yet the current from a fish has done it.

"The electrical discharges each endure, for a sensible period of time, resembling more those of a Voltaic apparatus, intermittent in its action, than those of a Leyden jar, which make their transit in an instant."

The shock given by the gymnotus resembles, it is stated, "that imparted from a large electrical battery, charged to a low degree, or that of a good galvanic battery of an hundred or more pairs of plates, whilst the contact of the connecting wires is completed only for a moment, the fish being able to repeat two or three shocks within scarcely a sensible interval of time."

"By experiments instituted by Faraday, for the purpose of comparing the intensity of the effects produced by the discharge of electricity from the gymnotus exhibited in London, and from electrical batteries, he arrived at the conclusion that a single medium charge from the fish was at least equal to the discharge of an electrical battery of fifteen jars, containing 3500 square inches of glass, coated on both sides, and charged to its highest degree."

It appears,* by an experiment made with the same eel, that a conducting wire *was rendered red hot* by the electric discharges developed by it.

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* Noad's Lectures, page 248.

"A common glass tumbler, having two small holes drilled on each side, was inverted on a wooden stand; two copper wires, with small brass balls attached, were passed through the holes. From each of them was suspended a strip of gold leaf, about one inch long, and one-eighth of an inch wide. The leaves, being arranged parallel to each other, were then approximated to within one-thirtieth to one-fortieth of an inch. On making contact with the eel, the leaves were not only attracted, *but were actually fused, scintillating in the most beautiful manner.*"

"The most powerful effect produced by a shock from the fish is described by Mr. Faraday to have been whilst the animal bends his head and tail around, in the position which is exhibited in figure 176, so as to form a portion of a circle; when the discharge takes place across the interval of space, as the string connects the two ends of a bow in a direct line. There being four electric organs in the gymnotus, whilst he is surrounded equally in all directions by water, all the particles of water and conducting matter contained therein, adjacent to the opposite sides of the fish, are affected at the moment of discharge, with circulating electric power. That this is the fact, was proved by a number of persons, on dipping their hands at the same time into the tub (the diameter of which was forty-six inches), who all received simultaneously a shock of greater or less intensity, accordingly as they were more or less approximated to the direct lines of the circuits of the currents."

The following account is given of the practical use which the gymnotus makes of its electrical powers for subserving his own wants, independently of his employment of them as a means of self-defence.

"A live fish, about five inches in length, was dropped into the tub. The gymnotus instantly turned around in a such a manner as to form a coil inclosing the fish, the latter representing a diameter across it; a shock passed, and there, in an instant, was the fish struck motionless, as if by lightning, in the midst of the water, its side floating to the light. The gymnotus made a turn or two to look for its prey, which, having found, he bolted it; and then went searching for more."

"Living, as this animal does, in the midst of such a good conductor as water, it seems at first surprising that it can sensibly electrify any thing; but, in fact, it is the very conducting power of the water, which serves to favor and concentrate the shock, by moistening the skin of the animal, through which the gymnotus discharges its *battery*."

When the gymnotus was touched by Mr. Faraday with non-conducting glass rods, or insulated conductors, he gave one or two shocks, felt by those who held their hands in the water, at a distance; but he soon ceased to exert his electrical powers, "as if he were sensible, from the obstructed mode of its escape from his body, that it did not act to produce the desired effect upon the body in contact with his skin. When touched, however, by the naked hand, he intelligently appeared to comprehend that a sensitive thing was present, and very quickly showed his willingness to employ his powers to astonish the experimenter."

It appears, from the account of the dissection of a Gymnotus Electricus, 3 feet 7 inches long and 14 inches in circumference, by Henry Letheby,* that "there are arranged along the interior of the body of the animal two pairs of electrical organs, composed of aggregations of regular cells of membranous tissues, extending obliquely from within outwards, and containing a peculiar albumino-gelatinous fluid. The dimensions of these cells are about 200 in the space of an inch." The dissector computed that "*the entire number of cells in the batteries, on both sides, is about* 550,000"! Mr. Letheby concludes that "there are many good and sufficient reasons for believing that the brain and spinal cord are the seat of power; and that the battery is no other than an apparatus for accumulating that power, as electricity is accumulated in a Leyden jar;—for the power exists only during life, and while the brain is active; and is voluntary, and dependent on the integrity (perfect conductibility) of the nerves. Direct irritation of the brain will effect a shock."

Mr. Letheby continues: "It seems most probable that the electricity is sent, AT WILL, from the brain or spinal cord, along the nerves, to be accumulated in the battery, from which, probably, after having acquired a certain intensity, it discharges itself through the circuit of the adjacent water, in preference to that of the animal's body."

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* Transactions of the London Electrical Society, page 367.

The fact that electric currents are actually excited and transmitted from one portion to another of the bodies of other animals than electrical fishes, admits of demonstration by means of the experiment illustrated by figure 11, page 181. The excitation of electric currents between the insertion of the stem and the opposite parts of the fruit, even in the mechanisms of vegetable bodies, has been already adverted to in treating of Organic Formations; so that this analogy appears to be extended to establish the fact that even the life power of plants, as well as of animals, is endued with a faculty of modifying the propagations of electro-dynamic action.

This belief is confirmed by the microscopic observations of the tissues of cellular plants, such as the mosses, lichens, and algæ, in the tubular cells of which are discoverable spiral coils, resembling that represented by figure 43, page 247, each series of spirals being wound in conformable directions. This arrangement is so precisely similar to that copied in all mechanisms designed for developing electro-mechanical action, that it affords the strongest corroboration of the electric functions of the organs of plants.

Among the most interesting investigations which have been made to illustrate the subject of the employment of galvanic currents to supply the place of *nervous influences* in performing some of the most important functions of life, appear to be the experiments made by Dr. Philips, published in the Philosophical Transactions. He severed the eighth pair of nerves (connecting the brain and breast) of some rabbits, when they speedily died, as if by suffocation. On applying one end of the conducting wire to the lower portion of the nerve, just below the incision in the neck, and the other end of the wire to the skin opposite to the stomach, so as to cause the current to flow along the nerves, the difficulty of breathing was prevented during twenty-six hours that the experiment was continued.

From the results of his numerous experiments, he was led to the conclusion that the action of galvanic electricity may be substituted for "effecting the formation of the secreted fluids from the blood, in the same way in which the *nervous influence* is applied to it; and that it is capable of occasioning an evolution of caloric from arterial blood, when the lungs are deprived of the nervous influence, and their functions are thereby impeded or destroyed. And when digestion is interrupted by withdrawing this influence from the stomach, *these two vital functions are renewed by exposing the proper nerves to the influence of a galvanic trough.*" Hence Dr. Philips supposes that galvanism is capable of performing all the functions of the nervous influence in the animal economy; but "obviously it cannot excite the functions of animal life, unless when acting on parts endowed with the living principle."

So numerous are the muscles in certain classes of animals, that it seems indispensably requisite that some general pervading principle, like that of electricity, must act upon them in *aggregated* numbers, as well as singly. It has been computed that in the animal structure of a single *pentacrinis* of the class of zoophytes, "there are more than 150,000 bones, each having its appropriate antagonist muscle. There must, consequently, be at least 300,000 muscles to be operated upon by the will of the animal.* As myriads of frogs' legs might be caused to become simultaneously contracted by the transmission of a single electric current through them all, so might this array of muscles be similarly acted upon at once, or in sections, by the transmission of electric currents subject to the will of the animal.

By the propagation of electro-dynamic action from electrical machines through the motor nerves, art may overpower nature in controlling animal motive-power, even in despite of the volitions of the mind or will; powerful as this control of electro-dynamic action has just been demonstrated to be in animal mechanisms.

Even in recently dead animals, where the controlling life power has for ever ceased, the electro-telegraphic apparatus of the motor nerves and muscles remain for a brief period capable of performing their regular functions, whilst subjected to the artificial propagation of electro-dynamic action through them.

Most surprising effects of this same action are producible by using powerful galvanic batteries to act on the motor nerves of human subjects. Many years ago, when these experiments attracted general attention from their novelty, they were frequently exhibited upon the bodies of recently executed criminals. The recollection of one of these courses of experiments, which I once witnessed, even now revives thrilling emotions.

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* Owen's Lectures on Reproduction.

The experiments were scientifically performed by a skilful surgeon. The most important nerves were laid bare, and successively subjected to contact with the connecting wires of a combined series of powerful galvanic batteries.

The propagation of the electro-dynamic action caused the arms of the subject to be uplifted, the fingers to move, and the fist to be clenched. The breast heaved with a convulsive movement, as if laboring heavily in an attempt to breathe.

By dexterously changing the positions of the wires to form contacts in rapid succession with the different nerves of the face, the muscular contractions exhibited fitful displays of the human passions. The eyebrows became alternately arched into a smile, and drawn down into a scowl. The nostrils became dilated, and the mouth contracted, as occurs on tasting of acids. The apparent apathy of an idiot was followed by the demoniacal expression of a savage. Fleeting gleams of the passions of revenge, desire and loathing, were so naturally counterfeited to the semblance of life, that it required recourse to the stern tests of reason and reflection to check the imagination, and to dispel the illusion that life had been resuscitated, particularly when the retracting uplifted eyelid disclosed apparent "speculation in those eyes." The executed criminal appeared to awaken, and cast a reproachful look upon us, for having succeeded in momentarily recalling the spirit back to a world, which it had just quitted in infamy and disgrace.

In closing these experiments, the electric action was finally propagated through one of the retracted legs of the subject, when the limb became instantaneously extended, as illustrated in the experiment with the frogs' legs, figure 12, page 184; when the feet were thrust violently against the stomach of one of the spectators, who was intently leaning over the table. The violence of this startling, personal salutation, demonstrated strikingly the efficient energy of electro-dynamic action in developing animal motive-power, as was ludicrously depicted in the horror-struck countenance of the gasping recipient of the unexpected kick from a dead man's foot.

MODE OF PROPAGATION OF ELECTRO-DYNAMIC ACTION, TO PRODUCE THE NATURAL CONTRACTIONS OF ANIMAL MUSCLES.

The preliminary truths being admitted of the continuous excitation of electro-dynamic action in the bodies of animals by the combustion of food in the lungs, and of the contraction of animal muscles induced by the presence of electrical currents, the next step in the progress of our inquiry is the discovery of the modes of excitation and distribution of these currents, through the conducting nerves of animal bodies to act upon their respective muscular systems. These mechanisms are ever ready to propagate impulses of mechanical force in obedience to the will of the invisible magician,—the immaterial essence of the mind.

The mode in which electricity acts in producing the contractions of animal muscles, and the consequent development of animal motive-power, appears as yet to have escaped minute scrutiny. It has been suggested by P. M. Roget, that the contraction or shortening of the muscles may be the result of the reciprocal attraction which ensues between two portions of conducting matter serving to transmit electric currents in similar directions, as has been illustrated by the contractions of a spiral coil of wire, figure 30, page 221. A piece of slender wire wound in corkscrew form, and placed in the circuit of a galvanic current, becomes instantaneously shortened or contracted by the lateral attractive forces exerted between each approximated coil, whenever the electric current is transmitted through it.

The discovery, by microscopic observations, of the spiral coils in the cells of plants, referred to at page 764, and the alleged discovery of similar arrangements of the fibres of animal muscles, strongly corroborate this supposition. A theory of muscular action has been suggested by Liebig, who ascribes the contractile force of the muscles to a principle set free by the chemical action or oxidizement of the animal tissues and blood, in the same way that electricity is set free by the oxidizement of zinc. He considers that the agency of the will serves to withdraw the protection of the vital power from these compound substances, and that chemical oxidations, and consequent development of impulses of mechanical force, ensue. One of the evidences of this chemical action is asumed to be the consumption of animal substances in proportionate quantities to the extent of muscular power brought into action, and expended.

The supposition that the chemical oxidation of the blood, and the development of impulses of mechanical force, ensues as a consequence of the voluntary withdrawal, by the controlling agency of the will, of the protecting vital power from the compound substance of the blood, appears to be untenable; because the regular decomposition of the blood goes on during sleep, when the volitions cease to exert any influence over the body.

If it be allowable to hazard conjectures, where facts are wanting to complete demonstrations, there appears to be reason preferably to suppose, that whilst the decomposition of food takes place in animal bodies, that there must be a continuous excitation of electric currents going on, such as occurs whilst the decomposition of the fuel goes on in a locomotive furnace, or zinc in a galvanic battery. It is only when the currents of galvanic batteries are diverted to traverse certain nerves, arranged like fine wires, that the muscular contractions ensue. It is therefore left for us to infer that the volitions do actually control the directions of the circulation of the electric action through the several nerves.

It has been found experimentally, that the exterior membranes lining the muscles of all animals are excited oppositely to the interior portions. In such case it would only be necessary that a slight electric current should be transmitted from the brain through the nerves, to induce a trifling degree of muscular contraction, in order to establish energetic circuits between these exterior and interior portions of the muscles; and the consequent development of energetic muscular contractions and of corresponding impulses of animal motive-power. It is stated by experimenters, that when the torpedo "wishes to give a shock, he first contracts himself," a fact which corroborates this supposition.

According to the results of Matteucci's experiments, continued upon the bodies of animals "during five months," he states, "they left me not the least doubt as to the conclusion," that it is in the muscle, and consequently in its organization, and in the chemical actions which are going on within its very structure, whilst it belongs to a living, or to a recently killed animal, that the cause of the current exists; and I cannot hesitate to regard the most simple occurrence of the muscular current to be from the tendon to the surface of the muscle." In his treatise on this subject, he arrived at the general conclusion, "that during the whole time the arterial blood is acting in the muscular fibre, the electric current becomes excited, and passes from the fibre to the blood, and thence to the surface of the muscles."

As the electro-dynamic action is developed by the decomposition of the blood, and not of the muscular fibre, it appears that Matteucci must have reference to a "negative" electric current, which "passes from the fibre to the blood."

To develope these currents, deep cuts were made across the muscles of recently-killed animals, and the points of coated wires were inserted like probes to the bottom of the gashes, whilst the other ends of the wires were brought into contact with the external surfaces of the muscles.

A small animal battery, composed of a number of the legs of frogs, was arranged with reference to a series of the external and internal surfaces of the muscle. By means of a battery of ten thighs, he caused a variation of from 30° to 40° of the galvanometer needle. A similar result occurred on substituting the muscles of various other animals, in place of those of frogs. He noticed, that "if you use piles formed of the muscles of different classes of animals, you will observe that the intensity of the current diminishes the more rapidly, in proportion as the animals, whose muscles are used, are of a higher grade in the scale of being. Thus it occurs, that piles formed of the muscles of fish, frogs, eels, and other cold-blooded animals, render manifest perceptible indications of the circulation of electric currents several hours after death; whilst those which are made of the muscles of birds and animals cease to do so at the end of a few minutes."

According to De La Rive's statement, "Dr. Prevost has succeeded in magnifying very delicate soft iron needles by placing them near the principal nerves, and perpendicularly to the direction in which he supposed the electric currents to move. The magnetizing of the needle took place at the moment a muscular contraction was induced, by irritating the spiral marrow." Thus a special excitation of a current ensues along the nerves whenever a special mechanical irritation is resorted to for the purpose of inducing it."

According to Graham's analysis of animal muscles, it appears that the acid phosphate of potash is an essential salt of the juice of flesh; and that the alkaline salt of the phosphate of soda is essential to the constitution of blood, to enable it to perform its functions. Hence it has been considered that the "probable function of the substances, which give acidity to the juice of flesh, and alkalinity to the blood, is the production of electrical currents. When we discover that two substances, one acid and the other akaline, in opposite negative and positive conditions, separated only by a thin membrane permeable to both (by *endosmose* and *exosmose* action), and in contact with muscle and nervous matter, as observed by Liebig, "we can easily see how electric currents may arise."

The facts which have been recapitulated establish, conclusively, the excitation of electro-dynamic action in animal bodies, and the propagation of it through the nerves, in obedience to the will. The propagation of this electric action must be effected in this case, as in all others, by establishing a circuit of electro-polarization. Considering the ends of the nerves terminating in the brain, to represent the ends of the far-extended wires terminating in the office of an electric telegraph, it becomes a curious question, whether the movements of the terminal points of the nerves, in closing the circuits, are produced by the immediate action of the will independently of electric agency, or intermediately through the agency of the "luciform vehicle," as suggested by Galen.

Although the connection between mind and matter may be inscrutable, yet the question admits of scrutiny, whether the mind acts directly upon the grosser matter of the ends of the nerves, to establish the connection between the surfaces and internal parts of the muscles; or upon the excited electric medium in the minuter circuits within the cells of the brain, to produce the movements which close the circuits of the ends of the motor nerves terminating in the brain. To establish more powerfully external circuits, as described of the use of *Relay Batteries*, in operating telegraphic wires, the minutest organic mechanisms of the tissues of thè brain might be adequate.

Microscopic observations and physiological investigati have not yet been directed to this question, to determine the above stated.

After ascertaining, by practical experiments, that musc contractions, and consequently animal motive-power, are im diately producible by the excitation of electric currents,—if admit that muscular contractions or movements of organic mations, are also producible at the pleasure of volition, ir pendently of electrical agency,—we must believe that there e two independent causes for producing precisely the same eff This would be an anomaly in the Mechanics of Nature.

Notwithstanding this fact of the paramount energy of tion of electric currents in producing the effects of musc contractions, Matteucci, in his treatise explanatory of the bable cause of the Nervous Forces of living beings, consi that electric excitation and discharges are rather the result t the precedent cause, of muscular contractions.

INVOLUNTARY MUSCULAR CONTRACTIONS.

Although the will has not an immediate influence in quic ing or retarding the movements of the muscles constituting throbbing of the heart, yet it is a singular circumstance that Imagination has an instantaneous influence in producing this sult. The pulsations become quickened by ardent desires, ho and fears, without any effort of volition to influence them.

To explain this remarkable phenomenon, we may sup that the more rapidly-bounding pulsations induce an acceler flow of blood through the lungs, and a quicker breath whereby the carbon of the blood is more rapidly burnt, consequently a more energetic development of physical forc available. It appears that this increased pulsation of the hea expressly designed to prepare the animal mechanism for m vigorous developments of its powers.

Considering that the pulsations of the heart are actually termitting spasmodic contractions of the muscles of that or produced by the intermitted propagation of electric action, it would be desirable for physiologists to ascertain if there be not some peculiar arrangements of the nerves of the internal mechanism of the valves of the heart, which may subserve the purpose of performing the functions of a self-acting electrical "current-changer." In the mechanical action of the opening and closing of the valves of the heart, subjected to the hydrostatic pressure of the blood, there is ample scope for some arrangement of the nervous tissues to constitute a perfect mechanism of the kind suggested, and adequate to producing the regularly-intermitted and involuntary contractions of the heart.

From the instantaneous mode in which the spasmodic pulsations of the heart are felt throughout the extremities of the upper part of the body, as well as at the lower extremities, where the hydrostatic pressure of the blood is more intense; and from the fact that in elastic tubes under moderate tensions of pressure, impulses imparted to fluids are transmitted *progressively*, to remote distances, there are strong reasons for believing that at the instant of the spasmodic contraction of the muscles of the heart, there ensues a simultaneous spasmodic action throughout the whole extent of the arterial system. The projectile force exhibited by the intermittent jets of blood, spouting from severed arteries remote from the heart, and in the upper extremities of the body, appear to be too energetic and simultaneous, to be entirely ascribable to the action of the muscles of the heart alone.

PHILOSOPHY OF THE EXHAUSTION OF MUSCULAR ACTION PRODUCING FATIGUE, WEAKNESS, AND SLEEP.

Inasmuch as even the "least movement of the finger consumes force," as observed by Liebig, and as the very heaving of the chest, and muscular contractions of the heart during sleep, also require the development of impulses of mechanical force, there must be a continuous excitation, to compensate for this continuous action of mechanical impulses.

When the impulses of mechanical force are developed in the body to an extreme degree, the excitation of the cause of the impulses does not keep pace with their exhaustion. The effort of volition ceases to control the cause of the contraction of the muscles; and finally, the whole power of controlling *voluntary* movements of the body ceases; the involuntary movements of the heart and chest absorbing all the remaining animal motive-power. When the exciting cause of muscular contractions thus wanes, the relaxation of energy is ascribed to *weakness* and *fatigue*. It is manifest that these phenomena are merely the result of the absence of an exciting cause.

This subject of the exhaustion of muscular energy, recognized by the term *fatigue*, does not appear to have attracted the scrutinizing attention of physiologists. It admits of explanation only, as a consequence of the exhaustion of the cause of muscular contractions; and deeming this cause to originate from electrical excitation, we may hence consider these phenomena as serving further to illustrate the subject of the motive-power of animals, as originating from electrical excitation. If muscular contractions be produced by the action of electric currents, then it follows that *fatigue* and *weariness* are the result of exhausted powers of electrical excitation.

The remarkable narration given by Humboldt of the exhausted powers of muscular action, or fatigue, of the electrical eels, in their conflict with the horses, driven into the water among them on purpose to exhaust their powers of action, serves admirably to illustrate the parallel between fatigue, and enfeebled powers of developing electrical action. He states that "gradually, the impetuosity of the unequal conflict became diminished, the EXHAUSTED eels dispersing—for they require a long repose and *abundance of food to repair the loss of the galvanic force expended*."

In the gradually waning power of muscular action, resulting from the continuous labors of the day, and in the nightly restoration of the powers of vigorous action, accumulated, as it were, during the motionless repose of the muscles, whilst the breathing and chemical decomposition of food in the lungs goes on uninterruptedly, we have apparently the resemblance of the accumulations of electrical excitation in connection with the surfaces of the muscles, as in the surfaces of Leyden jars, ready for future use. This probably constitutes the renovation of the exhausted powers of vitality "by kind nature's sweet restorer,—balmy sleep."

There is a very remarkable rigidity and tension of the muscles, which commonly takes place soon after death; so that it becomes difficult to bend the joints of limbs, which are readily flexible at the moment death ensues. This phenomenon appears to exhibit an interesting illustration of the sudden and general rigidity of muscular contraction, induced by the uncontrolled diffusion of electrical action.

Where there is no movement of muscles, there can be but a small extent of development of electric currents; and, consequently, we may anticipate a very trifling extent of decomposition of organic matter. In the state of the TORPIDITY OR HYBERNATION OF ANIMALS, vitality appears to become nearly extinct. Just sufficient excitation is sustained in the bodies of such animals to prevent the Zoo-dynamic supremacy from becoming extinct.

TORPOR, OR STUNNING EFFECTS, PRODUCIBLE BY PERCUSSION.

It is well known that a violent blow upon any portion of the nervous tissues of animal bodies produces a temporary suspension of the powers of sensation, and of vitality, which occurs when men and animals fall upon hard bodies, or when they are subjected to violent blows. A slight percussion of the brain is sufficient to prevent the nervous tissues of the body from transmitting the cause of motive-power to the motor muscles, or the cause of sensations from the muscles to this organ.

It has been shown, in the preceding pages, that the mechanical percussion of bodies is always attended with the development of electrical excitation. We cannot but suppose that a similar electric disturbance must ensue whenever the organic matter of living bodies is subjected to this kind of mechanical action. The process of exciting steel bars and needles by percussion with a hammer, has been described at page 472. The percussion produced by dropping steel needles, whilst held in certain relative positions, in regard to the westward circulation of the terrestrial electric currents, it has also been shown, will induce such an excitation of them, as to convert them into permanent magnets; and the further development of their magnetic forces admits of being reversed by percussion in falling, in particular positions. Admitting that such blows produce the effect of temporarily suspending, and of reversing, the latent electric currents naturally circulating throughout the muscles and nerves of living animal bodies, as they are supposed to circulate about, or among, the atoms of excited steel magnets; and admitting that muscular contractions are the results of the action of electric currents, we may rationally calculate that similar reversals or suspensions of such currents may be producible by percussion on the sensitively electroscopic tissues of the bodies of living animals. Intense pain may be the result of inducing an extraordinary tendency of such excited currents toward the brain; and a total insensibility might be anticipated from the percussion which reverses such currents.

On the same principle may be explained the torpor, convulsions, and death, which sometimes suddenly ensue from drinking cold water. In this case, we may consider that the sudden change of temperature in the stomach serves to induce thermo-electric excitations, which, for a time, may reverse or counteract the natural circulation of the currents, and produce such a paralysis of the functions of that organ, as may essentially prevent the further development of the phenomenon of life. The suddenness of the death which ensues from drinking cold water, whilst the external portions of the body are excited by extraordinary heat, appears, indeed, to be explainable on no other principle than the reversal of the established order of the latent circulating currents established between the stomach and the brain.

It might possibly be a beneficial experiment, for recovering persons prostrated by imprudently drinking cold water, to introduce the conducting wire of a galvanic circuit, inclosed within the India-rubber tube of a stomach-pump, or other non-conducting substance, into the sac of the stomach, for the purpose of applying this exciting stimulus to re-establish the disturbed functions of the nervous system, connected with this important exciting organ of the body.

MEDICAL EFFECTS PRODUCIBLE BY ARTIFICIALLY-EXCITED ELECTRIC ACTION.

The absolute necessity of the acquisition of a knowledge of the elementary constitution of the organs of the human body, and of the properties of the compound substances employed as medicines to affect them, has driven medical students to make many interesting experiments to promote success in the practice of the "healing art." The influences of the various kinds of compound substances, denominated *Drugs* and *Medicines*, are exerted by their contact with the organs of living bodies, in the same manner that the various kinds of elementary atoms produce electro-dynamic action on being reciprocally brought into contact with each other. For this reason, students of medicine have devoted themselves more particularly to the examination of the Chemical, or, as we have considered it, of the Electro-mechanical action, producible by presenting various kinds of compound substances in contact with living organs. For this reason, mankind are indebted to the labors and researches of members of the profession of Medicine for many of the most important discoveries in Chemistry and in the science of Electro-dynamics. The "gifts of Medicine to the Arts" have been truly munificent.

Vast numbers of experiments have been tried to test the advantage of the application of the exciting powers of electrical currents in curing various maladies, to which the human body is subjected. In some cases of morbid conditions of certain organs of the body, decided benefit has been found to be derived from the persevering application of electrical currents and shocks. These have proved a powerful stimulus to the activity of the vital functions, promoting glandular secretions, quickening the pulse, and promoting insensible perspiration. Rheumatic contractions and pains have been, in some cases, essentially relieved by this agency of electricity.

Great caution is requisite, however, in applying shocks from powerful electrical batteries to the head, so as not to affect the delicate tissues of the brain. It is well known by the familiar experiment of the destruction of the life of animals by the transmission of a shock from a Leyden jar through their heads, that deleterious effects may be thus produced. For medical purposes, the electrical currents are usually transmitted from the ends of pointed wires, so as to produce a breeze, or *aura*, as it is termed, upon the diseased parts; or a succession of sparks from the Prime Conductor of an electrical machine has been employed. But the most favorable mode of the application of the stimulating effects of electricity is accomplished by means of the magneto-electric apparatus, represented by figure 99, page 391.

But it seems probable that no very decisive results can ever be expected to occur from the application of electric currents to the *external* portions of the body. Until the electrical agency can be brought to act upon glands and *internal* portions of the body, in accordance with the plan by which they were originally designed to be operated upon, we have no more reason to expect that the respective functions of the animal organs will become stimulated thereby, than to expect that the various contrivances of the electro-magnetic machinery of the lecture-room can be operated by applying to them electric excitation in different ways from those originally designed to produce their calculated systematic operations.

Remarkable appearances of Insects, produced by means of long-continued Galvanic Currents.

Among the most surprising facts which have been published of the influence of electricity on animal life, is that stated by Mr. Crosse, as having occurred during a course of experiments, which he made with a view of decomposing and recomposing crystals of quartz, lime, malachite, and various other minerals, by the slow, and long-continued action of a galvanic battery. These experiments were announced at a meeting of the British Association, at Bristol, in 1836; and the author of them was introduced to the Geological committee, by Dr. Buckland, as "a philosopher who had made great discoveries by the use of a brick with a hole in it, immersed in a pail of water."

After detailing experiments showing the deposition of crystals of various mineral substances, decomposed and recomposed, between the surfaces of porous bricks kept in a state of long-continued electrical excitation, by means of sustaining galvanic batteries, Mr. Crosse noticed the appearance of excrescences from the sides of a stony mass, consisting of flinty matter.

After establishing the electrical current during eighteen days, these excrescences became enlarged, and seven or eight filaments, each of them longer than the excrescence from which it grew, made their appearance on each of the protuberances. On the twenty-second day these protuberances became more elevated and distinct, and on the twenty-sixth day, "each figure *assumed the form of a perfect insect*, standing erect on a few bristles, which formed its tail. Mr. Crosse supposed that these appearances were incipient mineral formations, until he plainly perceived these little creatures *to move their legs* on the twenty-eighth day. "In the course of a few days they separated themselves, and moved about with pleasure." In the course of a few weeks about a hundred of them made their appearance on the stone.

In stating these facts, Mr. Crosse observes, "I have never ventured an opinion as to the cause of their birth." The most simple supposition that occurred to him was, that they might possibly have originated from ova deposited by insects floating in the air, and hatched by electric action. In neither the water nor minerals used, could the same insects be discovered by the most critical examinations, and repeated experiments.

In subsequent experiments, the same insects (which it appears are found to be of the genus *Acarus*, a sort of spider, but of a species not hitherto observed) made their appearance in *electrified solutions of nitrate and sulphate of copper*, *of sulphates of iron*, and *sulphate of zinc*, *in fluosilisic acid*, *&c.* Mr. Weekes repeated some other experiments with *silicate of potash*, and *ferro-cyanuret of potassium*, inclosed beneath glass receivers, inverted over mercury, and with the greatest possible care, to exclude all extraneous communications, in some cases previously filling the receivers with oxygen gas. "After an uninterrupted action of an electrical current on these substances for upwards of a year, *insects have made their appearance*, in every respect resembling those produced in the experiments made by Mr. Crosse."

These insects, it will be noticed, are brought into existence and activity in *strong acid solutions*, which destroy the living principle in most other beings, and their origin, under such circumstances, has given rise to many curious speculations.

Mr. Noad states that Mr. Weekes, in some of his recent experiments, connected with the curious production of insects by the long continued presence of electrical currents, found swarms of *acari*, which continued to appear for three or four months; when a host of other kinds of insects followed, and, very shortly after, all the *acari* disappeared. "I am not certain," he says, "but I think they were *eaten* by the new comers, which are altogether of another genus. This I know, that they are very strange creatures."

That there must be some peculiarly stimulating power in electric currents, when long continued, to develope vital excitation, where none would otherwise occur, appears to be manifest from the result of these very curious experiments. But considering, as we have done, the originating cause of the excitation developed by the decompositions of the zinc in the galvanic battery to be due to solar excitation upon the organs of plants, in producing the charcoal and coke used in reducing zinc from its natural condition of an ore, to its temporary condition of a glittering metal, it may not be deemed any more wonderful that this secondary action of electric excitation should develope organic force, than that the primary action of solar excitation should quicken into life the myriads of insects which appear in the vernal sunshine.

PHILOSOPHY OF RENDERING ANIMAL MOTIVE-POWER MOST EFFICIENTLY AVAILABLE FOR LABOR, BY THE COMBUSTION OF ORGANIC FORMATIONS OF CARBON IN THEIR LUNGS.

In tracing the excitation of Animal Power, by means of the combustion of organic carbon and hydrogen in the lungs of animals, it will be here in place to consider the philosophical means of rendering efficiently available the greatest extent of impulses of mechanical force thereby developed, and available for useful purposes of labor.

The contraction of animal muscles being the immediate cause of the development of animal power, and the immediate cause of the contraction of animal muscles being dependent on the animal will, it consequently follows, as an unavoidable conclusion, that in order to render animal power most efficiently available, there must be a primary excitation of the WILL.

The prospect of the reward of food is sufficient to excite the Will of brute animals to exert muscular contractions in effective labor. Their limited intelligence is bounded by the prospect of a supply of their physical wants. They have no higher hopes than the gratification of their animal wants, nor more oppressive fears than the anticipations of bodily pain. The will of brute animals to labor is therefore excited to the utmost by the proffer of tempting food on the one hand, and of the terrific lash on the other. Thus, the dog may be induced cheerfully, or compulsorily, to exert his muscular powers in drawing loads for his master, and in turning the machinery of a churn, and of a spit; urged by the lure of hope to share in the products of his toil, or by the fear of suffering pain. Even the most humble of brute animals, the pig, may be induced to perform services involving the apparent exercise of refined sagacity of literary labors, by selecting alphabetical cards, to spell the names of many biped spectators, who are not able to accomplish the same task.

To the superior intelligence of man, higher inducements are requisite to excite the utmost energy of the will to labor, than a daily supply of food and raiment. Hopes of progress in improving both physical and intellectual conditions, are incentives of the human will, essentially necessary for developing the greatest extent of muscular energy. Despair, on the contrary, paralyzes the control of muscular contractions, in extreme cases even inducing stupor, or inability to move at all. As a substitute for Hope, the lash of the task-master is applied.

The excitement of the will to labor, induced by hope, being agreeable, is continuously sustained. The excitement induced by fear, is intermittent and spasmodic, ill-directed, and grudgingly applied.

Mechanical philosophy thus unmistakably demonstrates, that the greatest extent of animal power, producible by the combustion of food in the lungs, can only be developed by kindly exciting the will with animating hopes of adequate rewards, in the form of *wages*, for the performance of Voluntary Labor. Indeed, *Involuntary* labor appears to be a paradox in mechanical science, and essentially at variance with the interests of those who desire to obtain the greatest extent of the available products of human labor.

In voluntary labor there are found to be two elements to be considered, which affect the development of muscular action. Equivalents are estimated in specific extents of *muscular exertions*, and in specific extents of *time*.

When the element of time is excluded, full scope is given for the most vigorous muscular powers of laboring men. This result is accomplished by proffering rewards proportionate to the extent of muscular action, as in the familiar system of *job work*. Time, or *labor by the day*, is lost sight of in the incentive more speedily to obtain the stipulated compensation. About one-fifth greater extent of effective labor may be commonly calculated upon as the result of the system of *job work*, than where labor is paid for by the day, or by the *time* of continuance of muscular action.

But in work admitting of slightful execution, this efficient system requires the exercise of increased precautionary vigilance to insure the *quality* from becoming deteriorated by the haste to accomplish the *quantity*. It is by judiciously combining these elementary principles, with fair considerations that the laborer is worthy of his hire, that the greatest success is obtained by civil engineers.

The hope of obtaining advantageous exchanges of labor for wages constitutes the incentive of SELF-INTEREST, and the prime conservative principle of animal existence; and, it may be added, of social life.

There is a wide difference between *Self-interest* and *Selfishness*. The former implies the promotion of one's own happiness and advantage, which is most effectually done by promoting the happiness and advantage of others; whereas *Selfishness* implies a desire to accomplish the same result without reference to the happiness of others. *Self-interest* is not, therefore, promoted by selfish conduct. Gross ignorance of *true Self-interest*, on the contrary, is manifested by selfish persons; and their frequent disappointments in their unsuccessful pursuit of happiness, if strictly noted, would prove a sufficient warning for all men to avoid this erroneous course. It is an ignorance of true self-interest,—a mistaken idea of what is conducive to well-being, which deludes men into the belief that permanent positive good can ever result from the infringement of any of the physical or moral laws which govern our nature. The immediate apparent fruition of enjoyment of inebriety, or of success in dishonesty, theft, or robbery, does often unfortunately mislead men into the unhappy error of supposing that such actions are really sources of good, or beneficial in promoting Self-interest; whereas, on the contrary, these causes are all thoroughly condemned by the results of human experience, and branded with the name of *faults*,—a word derived from the original Latin term, FALLO, *I deceive*, denoting the fallacy of the judgment which arrives at conclusions so pernicious to Self-interest.

Self-interest, and success in the pursuit of happiness, are therefore immutably based on the government of the original mechanical impulses excited by the volitions, in accordance with the truly divine precept of "good will to men."

By following up this train of reasoning, it appears that the "Mechanics of Nature," in all its practical bearings, is really the systematic carrying out of a sublimely conceived design to promote the greatest happiness of the greatest number, and thus to extend throughout infinite space a benign plan of UNIVERSAL BENEFICENCE.

ON THE COMPARATIVE VALUE OF HUMAN LABOR IN DIFFERENT COUNTRIES.

It appears to be a frequent subject of surprise to intelligent men, that there should exist extraordinary differences in the pecuniary rewards, or prices, paid for the work of a laboring man, in different parts of the earth's surface, when there is so little difference in the pecuniary prices of the food which constitutes the basis of the support of laborers.

In the United States, the daily wages for a laborer is abou one dollar;—in England, seventy-five cents;—in France, about three francs, or fifty-six cents;—in some parts of Austria and Poland, about half of the last-named price;—whilst in the East dies and China, only ten or twelve cents constitute the value of the labor of a man for one day. A given quantity of flour and rice contains about an equal amount of the organic substances of carbon and hydrogen; which, when burnt in the lungs of laborers in either of the above-named countries, will produce about an equal amount of impulses of physical force. This being admitted, it becomes an interesting investigation to trace the cause of the very remarkable difference in the wages paid for a day's labor in different countries?

In estimating the price of human labor, constituting *wages*, it becomes necessary to take into consideration another element of power, distinct from mere physical force, viz., *a knowledge of the most effective modes of rendering physical force advantageously available.* By combining the comparatively feeble physical power of a man with a knowledge of the laws of action of natural motive-power, as applied in imparting impulses through machinery, the result of a day's labor admits of being augmented, in many cases, more than an hundred fold. It follows, as a necessary consequence, that in estimating the comparative value of the daily labor of the inhabitants of different countries, this combination of the extraordinary power of KNOWLEDGE must be taken into account, as productive of more exchangeable values than brute force unskilfully directed.

In the labors of agriculture, the inhabitant of an isle of the Pacific Ocean may exert the same amount of physical force with his hoe composed of a pearl shell, as a laborer exerts in holding a plough in England, or in the United States; but the combination of the more effective power of the horse, with the more effective agency of the machine operated by his motive-power, stamps a twenty fold greater value on the labor of the ploughman, as measured by a twenty fold greater production of the food which constitutes a common standard of the relative value of a day's labor. So also in the labor of Manufactures, it is well known that in ages past one man in England has actually produced more value in spinning cotton fabrics, than several hundred persons in India, with the single spindle and distaff. And this contrast may be extended throughout nearly every other branch of human industry, in favor of the greater exchangeable values produced in England.

In the northern States of America, judging from personal observation, there is gained by extraordinary advantages of water-power, and of intelligently applied labor, combined with improvements of machinery, and cheap fertile lands, about as much more of the exchangeable value of agricultural and manufactured products, as is equivalent to the difference between the wages paid in England and in the United States.

An intelligent and experienced navigator has stated to me, as the result of his experience in executing the same amount of labor, in the repairs of his ships in Holland, France, England, and the United States, and the British East Indies, that the cost of the labor has averaged very nearly the same, although the rates of the wages of ship carpenters vary in these several countries from about 55 cents to 200 cents per day.

A "servant of all work," in England and in the United States, performs the labor of three or four servants in a household in Calcutta and Canton; and receives three or four fold the amount of wages.

Thus it appears that the pecuniary standard of the price of wages for a day's labor in different countries, is a pretty accurate standard test of the relative available advantages of natural motive-power combined with the intelligence and mechanical knowledge existing in such countries.

CAUSE OF SOLAR EXCITATION, AS THE SOURCE OF THE CONTINUOUS PROPAGATION OF ORGANIC AND INORGANIC ACTION.

"Its own revolvency upholds the world."—COWPER,

Having thus far traced to the electro-dynamic action of the sun the originating cause of the variously modified static conditions of groupings of atoms into Inorganic and Organic Formations, and the variously modified resultant electro-dynamic impulses propagated therefrom on every recoil of such groupings from constrained static conditions to natural static conditions, it next becomes a most interesting and important question, in pursuing these investigations of the sources of Natural Motive-Power, *What sustains the electro-dynamic excitation of the sun?*

Although this question may be deemed as somewhat transcending the present limits of physical science, yet a philosophical consideration of it cannot be finally avoided, when the fact is established, that the electro-dynamic action of the sun controls the states of relative motion and rest of all the matter of the planetary system.

Sufficient facts have been detailed in the previous pages to warrant the deduction, stated at page 311, that there cannot occur the movement of one body near another, without disturbing the electro-static condition of both bodies, and without producing the consequent development of electro-dynamic action and reaction between them. In treating of the reciprocal mechanical action of bodies in motion near each other, it has been there also premised, that the science of astronomy teaches us that all the worlds of the planetary system are actually in a state of inconceivably rapid motion. The original design of their rapid motion must have been to excite and sustain a continuous electro-dynamic action, not only between the masses at sensible distances, but also between all their component atoms at insensible distances. This action is recognizable by the general terms of Attraction, Repulsion, and Polarity, and by the specific terms of Light, Heat, Electrical action, Gravitation, Cohesion, Magnetism, &c. It remains now to illustrate these conclusions by further details of facts.

That the revolution of the earth on its axis induces a disturbance of its electro-static condition, and the excitation of electric currents from east to west about the earth's surface, has been demonstrated by figure 27, page 229, and by figure 45 page 250. Even the passage of clouds over the surface of the earth has been discovered to produce electric currents, traversing the fields beneath them.

"There is no distance so great that inductive action cannot take place through it," Professor Faraday affirms, (Experimental Researches, page 411.) In corroboration of the truth of this assertion, he quotes experiments indicative of the probability that the electro-dynamic action would "appear at a distance of

200,000 miles in a second of time;" and that a power, equal to that of a destructive thunder-storm, adequate to rending oaks and massive rocks, and to producing electrical attractions and repulsions of incredible extent, might be propagated to the distance of the moon from the earth, in this brief interval of time.

There is no imaginable reason why the heavenly bodies should have been put in motion with the velocity of about a thousand miles per minute in the space of the heavens, instead of being stationarily fixed in determinate positions at rest near each other, unless it be this special design of inducing continuous excitation and propagation of electro-dynamic action.

After the creation of the worlds of matter in the free space surrounding the great central orb, the sun, at the instant they began to move in obedience to Omnipotent will, their electro-static conditions must have been disturbed; and there must have commenced simultaneously a mechanical action originating from the divine will. This action must have necessarily become propagated through the medium of electric matter pervading all space, not only between the heavenly bodies at sensible distances, but also between the component atoms of each orb.

The facts of the reciprocal action and reaction propagated through the medium of electric matter, have been illustrated in every chapter of the preceding inquiry into the originating source of Natural Motive-Power, both theoretically, and by the test of practical experiments with various kinds of artificial apparatus. Representations of the phenomena of the Attraction and Reciprocal revolving movements of portions of inert matter, have been illustrated, such as take place among the natural "mechanisms of the heavens." Even the constant maintenance of the complex rings about the central orb of Saturn, appears to exhibit an analogy to the helix inclosing the bar of iron, represented by figure 38, page 244.

When it is considered that the exterior ring of this planet is nearly 200,000 miles in diameter, whilst its thickness has been estimated at only about 100 miles, these relative dimensions may be compared with that of the revolving plates, figures 66 and 67, whereby intense electric currents are excitable. The movement of the exterior ring of Saturn has been computed at the extreme velocity of about 1000 miles per minute; with its inner edge separated from the body of the planet by a space of only about 2000 miles. On beholding this revolving apparatus lighted up for human observation in the evening sky, we may well feel inspired with the most enthusiastic admiration of the wonderful mechanical arrangement of its parts, so balanced in space, that these magnificent circles, with their inclosed planet, are sustained "with an equilibrium in which destruction and permanency are ever contending."

The rapid revolution of the earth on its axis, it has been shown, induces the circulation of electric currents from east to west about its surface, by the reaction of the sun; which reaction must be equal to the action, in accordance with the established law of mechanical science. There must also be an equal action of the currents about the other planets, exciting reacting currents about the solar disk. Hence it admits of theoretical calculation, that the intensity of the electro-dynamic reaction of the sun must be represented by the sum of the intensities of the action of all the planets revolving about it.

The solar system, in this view, becomes resolvable into a vast electrical orrery, owing its excited electro-dynamic powers to the first impulses impressed upon the several planets by the Creator. It represents also an orrery, combining within the very plan of its operation a *self-sustaining* cause of the continuous propagation of electro-dynamic powers, based on "its own revolvency," as anticipated in the almost prophetic verse of Cowper.

The preceding facts afford a rational explanation of the electro-mechanical action and reaction, constituting the light and heat of the sun, as also a rational basis for the estimation of the durability of solar heat and light; for *whilst the planets continue to move with their present velocities about the sun, its power of propagating electro-dynamic reaction must continue undiminished.*

Physical science becomes thus relieved of the embarrassing question of the source of the supply of fuel necessary for maintaining combustion, as a cause of solar heat and light; whilst there is at the same time furnished a systematic plan in tracing the establishment of all the mechanical static and dynamic conditions of terrestrial matter, to the variously modified propagations of the original impulses of mechanical force, imparted by the Creator to the worlds of the planetary systems in the infinite space of the heavens. Mechanical Philosophy brings us to the unfaltering recognition of the sublime truth, that the GREAT FIRST CAUSE IS THE ORIGINAL SOURCE OF ALL NATURAL MOTIVE-POWER.

THE ELECTRO-DYNAMIC EXCITATION OF THE SUN CONSIDERED TO BE COMPATIBLE WITH THE OCCUPANCY OF ITS SURFACE BY LIVING BEINGS.

By reasoning from analogy, there appear to be very strong reasons for entertaining the belief that the sun may not be a vast torrid globe of consuming fire, and of billows of ignited lava, as was once generally supposed. For the fact is experimentally demonstrable, that all the characteristic phenomena of intense light and heat, rivalling the effulgent disk of the sun itself, are actually producible between two charcoal points, without igniting this readily combustible substance. This familiar experiment proves that even were the mass of the sun composed of a material fuel, as readily inflammable as charcoal, and were its surface enveloped by an atmosphere containing as much oxygen as the earth's atmosphere contains, it might remain unignited, whilst its atmosphere is surrounded by sufficiently intense electric currents to produce the dazzling action on the eyes of sentient beings, which has been described at page 626.

The external portion of the earth's atmosphere is occasionally brightened by a resplendent illumination of electric excitation, recognized as the Aurora Borealis; whereby the canopy of the heavens becomes lighted up, as it were with radiant flames. To the eye of a sentient being stationed at the distance of the moon from the earth, this planet would exhibit at such times a self-luminous appearance of waving billows of light. The phenomenon of this excitation has been ascribed (page 624) to the electro-dynamic reaction of the sun.

If the sun produce this electro-dynamic excitation of the earth's atmosphere, there must be an equal reaction of the orb of the earth on the sun's atmosphere, in accordance with the established laws of mechanics, as has been stated in the preceding chapter.

These analogies are corroborated by the discovery, by Wilson, of the shaded spots on the sun's disk, which are deemed to disclose to view the real opaque surface of that orb, denuded of the excited electric atmosphere. The constant agitation of this electric atmosphere has been considered by Herschell as resembling a stratum of clouds, forming "an exterior stratum of *self-luminous matter*, which constitutes the commonly-visible solar disk."

That there may exist a strongly-excited state of the electric atmosphere, environing habitable space, without disturbing the nicely-balanced action and reaction between the bodies existing within it, has been practically demonstrated by the experiment of Professor Faraday, described at page 440. When the external coating of an insulated metallic chamber was charged so highly as to dart off long sparks, he states "that no perceptible influence of this highly-excited electric condition of the external surface could be detected by me within the interior, by means of electroscopes, or of any other instruments employed as tests of the actual presence or excitation of electricity."

These analogies appear, therefore, to warrant the belief, that the great mass of matter constituting the globe of the sun may not be a solitary exception to the system of the general diffusion of life and of enjoyment of living animals, which has been shown to pervade all terrestrial matter; and that as every leaf of the forest, and the drops of water on our planet, teem with animated beings, so the sun itself may likewise teem with animated beings.

Considering, too, that the phenomena of HEAT and LIGHT are ascribable to electro-dynamic excitation, we may be authorized to believe that the globe of the sun may not only be habitable, but even that its inhabitants may be blessed with more genial skies than our own, having no wintry storms and nights of gloom to obscure their ever sunny landscapes.

A SELF-REGULATING, OR COMPENSATING PRINCIPLE OF ELECTRO-DYNAMIC ACTION AND REACTION, CONSIDERED AS GOVERNING THE VELOCITY OF THE MOVEMENTS OF THE PLANETARY SYSTEM.

The establishment of a self-compensating principle, serving to control the movements of the mechanisms of the heavens with the regularity of the operation of a steam-engine governed by the centrifugal force of the ball pendulum, admits of illustration, by referring to the cause of the failure of the various kinds of electro-magnetic engines, which ingenious men have devised, in various attempts to render available electro-motive power as a substitute for steam power. This principle has been described at page 685; where it has been shown that reacting secondary currents subserve the purpose of a self-compensating principle, regulating the speed of movement of the approximating and receding parts of all mechanisms impelled by electro-motive agency. Thus, by observation of the laws governing the movements of humble artificial apparatus, we are permitted to deduce laws which may govern the whole planetary system, constituting a vast natural mechanism in the heavens, controlled by electro-dynamic agency.

The preceding calculations serve to relieve the mind of the embarrassing supposition, that a constant charge and watchfulness devolves on the Creator of the mechanisms in the heavens, to guide them in their courses, and to sustain their equable revolving movements. For it is derogatory to the attributes of an Omnipotent and Omniscient Creator, to entertain the idea, for a moment, of his subjection to the burthen of the earth-like cares and watchings of a human engineer, in order constantly to sustain and regulate the movements of the countless myriads of celestial mechanisms, which glitter as "star-dust" in the depths of space. Indeed, the preceding calculations, founded on the basis of partially disclosed facts of the continuous propagation of mechanical action through the medium of electric matter, teach us that it could only have been necessary for the Creator to have given the first impulse to each of the worlds of matter in the free space of the heavens, in order to have propagated a simultaneous development of electro-mechanical impulses between the masses of matter constituting such worlds, and all other adjacent matter, in the various forms of Attraction, Polarity, Light, Heat, &c., as has been recapitulated in detail throughout the preceding pages.

Electro-dynamic science serves also to relieve the mind of doubts formerly entertained of the durability of the excitation of the sun; which must propagate its reaction undiminished, so long as the planets continue to revolve around it with undiminished velocity. And as matter put in motion cannot stop itself, this velocity must continue until arrested by the same Power, which originally established it.

The states of motion and rest of terrestrial matter have thus been traced to the electro-dynamic reaction of the sun; and this reaction has been traced to the impulses imparted by an INTELLIGENT IMMATERIAL FIRST CAUSE, as the originating source of NATURAL MOTIVE-POWER.

At this bourne, which bounds the limits of the material world, the further physical explorations of mechanical science must be terminated. But the investigations of the states of rest and motion of terrestrial matter cannot be complete without taking cognizance of the power of modifying the propagation of mechanical impulses, possessed and exercised by CONTROLLING INTELLIGENCES. Immaterial as the essence of Intelligence is admitted to be, and therefore removed beyond the immediate province of the investigations of mechanical science, yet at the instant the states of motion and rest of any portion of matter become affected thereby, the consideration of this paramount influence must manifestly be recognized by mechanical science, as a most important essential cause of *modifying the directions* of the impulses of NATURAL MOTIVE-POWER.

The simple facts which have been detailed of the systematic arrangements of groupings of atoms into the formations of vegetable and animal mechanisms, designed for developing locomotive impulses of Organic Action, conclusively proves the existence of a knowledge of effects producible by mechanical causes. This prescience constitutes the idea of the pre-existence of an IN-

TELLIGENT FIRST CAUSE, as well as of a MECHANICAL FIRST CAUSE of the development of impulses of mechanical force, adequate to producing all the observable relative states of rest and movements of passive matter.

The movements of the organic formations of animals in every direction, with developments of impulses manifesting a prescience of mechanical effects producible by mechanical causes, also conclusively prove that various grades of SECONDARY INTELLIGENCES, as well as of SECONDARY MECHANICAL CAUSES, exist in connection with such mechanisms.

ORGANIC ACTION, OR THE MODIFICATION OF MECHANICAL IMPULSES BY THE ORGANS OF ANIMALS, CONSIDERED AS MECHANICAL TESTS OF THE EXISTENCE OF SECONDARY INTELLIGENCES IN CONNECTION WITH TERRESTRIAL MATTER.

The systematic movements of atoms of matter, grouped into various organic formations, are the only palpable tests of the existence of INTELLIGENCES on the orb of the earth. Were all organic formations of animal bodies perfectly motionless, and were a solitary human intelligent being permitted to survey them as fixed statues of Parian marble, he might regard them as devoid of the power of *thinking;* which logicians deem the strongest adducible proof of the existence of Intelligence in connection with terrestrial matter. The power of controlling the direction of the movements of the matter, organized into animal bodies, constitutes LIFE; the cessation of this power is denominated DEATH.

The practical experience of every Intelligent being affords conclusive proof of the actual capability of an innate power of the will to produce contractions of the muscles, and the consequent control of mind over matter, in the specific form of Animal Motive-Power. There must, therefore, be a material first link, a *punctum saliens*, where the communication between mind and matter is established; although, as in the blended hues of the rainbow, it may be difficult to designate where the dividing line may be. Electric matter, in the preceding chapters, has been considered as constituting the sparkling link, which connects together material and immaterial essences.

When this connecting link is once broken, the intelligently directed movements of the atoms, grouped into organic formations, cease for ever, to human observation; and these formations become resolved into the original inorganic formations of fluid air and water, as has been recapitulated. Hence, all secondary Intelligences are denominated FINITE.

That the intelligences governing the movements of living organic matter are both *immaterial* and *finite*, is manifest from the facts, every day sadly disclosed to our notice, of its ceasing to wield the sceptre of its control over the material mechanisms, in which it is embodied. Whilst every atom of the decomposing mechanism of the human body may be traced throughout its changes, from solids to fluids and gaseous states, without eluding the grasp of the chemist, the disembodied Spirit of Intelligence disappears from this earth, without leaving a wreck behind.

Even the practice of moral duties, and the exercise of the moral virtues are founded on Mechanical Action. The god-like virtue of beneficence consists in kind *actions;* and the mission of the Redeemer was "to go about *doing* good." The tests, also, of religious faith are emphatically "*works.*"

The Intelligence innate in connection with the organic formations of human beings is of a most limited grade; but it appears to be almost infinitely improvable by training, or *education.* The Intelligence innate in brute animals, on the contrary, is more nearly perfect at their birth, and less susceptible of subsequent improvement, being principally limited to sagaciously controlling the Organic Action for the procurement of necessary food, for the avoidance of physical injuries, and for the propagation of the species. So perfect and keen are the innate intelligences of brute animals, that men are found to wear a fox's tail affixed to their caps in token of achieving a triumph over the sagacity of the fox, and vauntingly to narrate incredible stories of capturing fishes.

This subordinate grade of intelligence in brute animals, has been denominated INSTINCT.

In treating of the Organic formations of Plants, it has been noticed (page 104), that they are endowed with a grade of instinctive powers, adapted to their several local conditions. These powers are remarkably developed in the sagaciously-directed extension of their roots in pursuit of aliment.

Human intelligence, from the most humble grade of instinct, at birth, becomes gradually developed and improvable. Although each human intelligence may have only a brief and finite existence in connection with the Organic formation of the animal mechanism, and the progress of the improvement of the individual may be lost when this connection is dissolved by death, yet, by traditionary and recorded communications, each succeeding generation of human intelligence has the advantage of the improvements in knowledge acquired by preceding generations.

This accumulated knowledge is denominated SCIENCE, a term derived from the Latin word, SCIO, *I know*.

The knowledge thus acquired by mankind is classified as SCIENTIFIC ATTAINMENT, in contradistinction to innate instinctive knowledge.

The advancement of physical science is protracted by the fallibility of human intelligence, and by the difficulty of forming truthful judgments of facts by means of the electroscopic nerves of sensation and perception, as has been previously narrated. And then, again, the acquisitions of individual knowledge are dissipated at the termination of the allotted threescore and ten years, constituting the usual duration of human faculties; as the freight of treasures of a bark are wrecked on the ocean shore. Science gathers upon the strand the waifs from each wreck, which would otherwise be for ever lost, and records them as accumulated additions to the stock of human knowledge. Each successive acquisition, like each successive wave on the rising ocean tide, progresses a little further than the last. Thus, there is established a law of PROGRESS OF HUMAN INTELLIGENCE.

With this gradual increase of human knowledge, we are led to the consideration of a UNITY OF PROGRESS IN INTELLIGENCE during prolonged periods of time, such as have been referred to at page 138, in treating of the duration of the supply of mineral coal, as constituting a Geological cycle.

Throughout all the mechanisms of the heavens, there is established a systematic return of every great orb to the same place, to recommence the same career, after the lapse of determinate periods of time. "Periodicity,—the great law of Astronomy," as Herschell has remarked, "is the continual reproduction of the same phenomenon in the same order, at equal intervals of time."

The *Periodicity* of our planet has been denoted by geologists by a beautiful allegorical reference to the cycle of a day, commencing with the incipient dawn, termed the EOCENE PERIOD. This term is derived from the Greek word EOS, *dawn*, and KAINOS, *recent*. The several terms, MEIOCENE, PLEIOCENE, and PLEISTOCENE, each designate a later, and still later development of the Inorganic and Organic formations of our planet, up to the present time.

That a similar Periodicity characterizes the development of human intelligence, appears to be remarkably demonstrated by the rapidly progressive advancement of the Intellectual Cycle by fresh acquisitions of science during the past half century. The supplanting of races of savage men throughout whole regions of the earth's surface, which were quite recently unexplored wildernesses, by men exercising higher intellectual powers, and the rapid diffusion of knowledge by means of the printing press,—all conspire to show the brightening of the dawn of Intelligence,—of the EOCENE PERIOD OF THE HUMAN MIND.

But when we attempt to apply the present rate of advancement to embrace progressive developments of human intelligence extended to the termination of a geological cycle of hundreds of thousands of years, we may well imagine that the Intellectual and Geological cycles may alike finally run out their allotted course; and that another pause may again occur for the renewal of exhausted formations of fuel, and of the primeval state of intelligence, such as has been ascertained to have existed recently in the history of this planet.

These calculations of a Periodicity of physical and of intellectual cycles, may appear at present like dreamy speculations, presenting dim and misty outlines when viewed through the remote vista of future years; yet they are based upon facts recorded in stones,—in "the medals of creation," and disclosed by footprints on the shores of antediluvian oceans.

THE OCCUPANCY OF SPACE BY MATTER, AND ITS CHANGE OF PLACE IN SPACE, CONSIDERED AS MECHANICAL TESTS OF THE EXISTENCE OF AN ABSOLUTE INTELLIGENT POWER.

"As the Deity is the supreme first cause, from whom all other causes derive their whole force and energies, it would be an unaccountable omission to exclude him only out of the universe."—Newton.

The glorious orbs of matter, which appear pursuing their solemnmarches through the evening sky, constituting the "mechanism of the heavens," are adducible by the science of mechanics, as silent witnesses, to prove the existence of an Infinite Power, necessary to cause their occupancy of space, and their continuous change of place in space. The wonderfully varied contrivances of innumerable mechanisms of vegetable and animal bodies, which "live and move and have their being" on the surface of the earth, are also adducible by mechanical science, as conclusive proofs of the existence and practical exercise of Infinite Intelligence. As remarked by Agassiz, "facts now as well established as facts of this nature can be, point out to us, as with the finger, the direct intervention of a Creative Intelligence, anterior to the existence of all beings; who has ordained their relations, determined their development, and directed their successive appearance up to the establishment of the order of things, which now prevails in the world."

The existence of an Intelligent First Cause of the occupancy of space by matter, and of the original movements of matter in space, appears, therefore, to be one of the primary truths established by the science of mechanics, which must always be kept in view during every research of physical science. Nor is this a novel conclusion; for even an ancient heathen philosopher, Aristotle, remarks, in his treatise "De Mundo," that "to consider of the world without saying any thing about its Author, would be impious."

The LAWS OF NATURE are evidently ordained by the Great First Cause, expressly for the systematic regulation of the action of the Organic and Inorganic forces, which operate the mechanism of his material universe, and not as laws to limit his own will and powers;—for we cannot for a moment suppose that Almighty Power can fail of transcending, in paramount energy of action, the subordinate secondary forces, which derive their very existence from his will. As observed by Dr. Watts, in his treatise on Logic, "There is but one Being, which includes existence in the very essence of it, and that is God. All other bodies exist, or cease to exist, as it may please him." This transcendency over the Laws of Nature constitutes ABSOLUTE POWER.

To this ABSOLUTE POWER we have now finally traced THE ORIGINATING SOURCE OF ALL NATURAL MOTIVE-POWER.

THE END.

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